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Determination of Proximate Composition and Lipid Deterioration in Various Parts of the Gibel Carp (*Carassius gibelio*)

Koray Korkmaz[1,*], Bahar Tokur[1], Bilge Bilgin Fıçıcılar[1]

[1]Department of Fisheries Engineering Technology, Fatsa Faculty of Marine Sceience, Ordu University, Ordu, Türkiye.

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Corresponding Author
E-mail: koraykorkmaz@odu.edu.tr

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Abstract

This study explores the potential utilization of meat, scales, viscera, and bony structures of gibel carp (*Carassius gibelio*), an invasive and economically underutilized species from the Black Sea, as alternative lipid sources for human consumption and functional ingredients in animal feed. The nutritional composition analysis showed significant differences among tissues: the meat contained 14.98% protein and 1.43% lipids, while the viscera exhibited the highest lipid content (22.38%) but the lowest protein level (1.08%). The scales had the highest protein (21.31%) and ash (9.07%) contents, while the bony structures contained significant levels of protein (18.38%), lipids (2.59%), and ash (7.20%). Lipid oxidation parameters indicated that the viscera had the highest peroxide value (3.8 meq O_2/kg), whereas the scales had the lowest (2.47 meq O_2/kg). Thiobarbituric acid (TBA) and free fatty acid (FFA) values demonstrated better oxidative stability in meat and bony structures compared to the viscera. These findings demonstrate the potential of utilizing Gibel carp by-products as alternative raw materials for a variety of applications. This approach supports sustainability and the principles of the circular economy, providing an innovative way to turn an invasive species into valuable resources.

Introduction

The recovery and utilization of food waste are increasingly encouraged, particularly in developed countries (Laso et al., 2018). By-products generated during food processing emerge in varying amounts as a result of processes applied in the food industry. Many types of food waste represent valuable nutritional resources due to their protein, carbohydrate, and lipid content (Prandi et al., 2019). The latest FAO assessment reported that global waste generated by fisheries, including by-products, is estimated at approximately 27.85 million tons annually (FAO, 2022). The utilization of by-products obtained from the food industry and the development of new functional products have garnered significant attention due to their potential to provide substantial economic benefits on an industrial scale (Cotabarren et al., 2019). As the global population continues to grow each year, the search for new food sources and their production has become a significant issue. Seafood by-products are not merely pollutants but valuable resources for recycling. Utilizing these by-products is essential to the production of high-value-added products for the national economy and to preventing environmental pollution. Fish discards and by-products generated in fish processing industries pose ecological and environmental challenges (Morales-Medina et al., 2016; Korkmaz & Tokur, 2022). The fish processing industry generates over 60% of by-products as waste, including skin, heads, viscera, trimmings, liver,

skeletal systems, bones, and eggs. Currently, a significant portion of fishery products is either discarded or used for low-value products. However, these by-products can serve as an excellent resource for producing various value-added products such as fish oil, proteins, amino acids, and biodiesel. This waste material contains high-value molecules with numerous potential applications in the production of value-added products, including polyunsaturated fatty acids, amino acids, enzymes, peptides, minerals, and vitamins (Rigano et al., 2021; Donnarumma et al., 2021). Valuable compounds such as gelatin, pigments, antifreeze proteins, and ω-3 fatty acids obtained from by-products can be used as functional ingredients in food matrices (Sindhu et al., 2019; Yin et al., 2014). Many food wastes, due to their protein, carbohydrate, and lipid content, are recognized as valuable nutritional resources (Prandi et al., 2019). A significant amount of by-products is generated in the fish products industry, estimated to account for approximately 75% of the total fish weight retained after the filleting process (Hou & Regenstein, 2004; Rustad et al., 2011). Despite containing numerous valuable components, fish by-products are often utilized as fish feed, silage, or fertilizer, which hold relatively low commercial value (Gómez-Guillén et al., 2002; Muyonga et al., 2004; Rustad et al., 2011). Alternatively, they may be discarded as waste into the sea or deposited in solid waste landfills, actions that are known to have adverse environmental impacts. The efficient utilization of by-products generated during the processing stage is crucial for preventing environmental pollution, producing high-value-added products, and enhancing product diversity.

The oil extracted during fishmeal production is used as a raw material for fish oil production (Hardy & Tacon, 2002). However, the oil obtained from this process is of high quality, which increases costs. As an alternative, by-products have started to be utilized to produce environmentally friendly and high-value-added products. Fish skin, bones, fins, and scales are significant by-products of fisheries and aquaculture. In recent years, a key concept emerging in the changing global landscape further supports the purpose of our study. The circular economy is an industrial term that emphasizes transformation and recycling over the traditional production, use, and disposal processes in industrial economics. Profitability is measured by how much can be recovered from recycling and how effectively waste can be converted into new resources. The concept of the blue economy in this context encompasses all industries and sectors associated with oceans, seas, and coasts. The blue economy model promotes a range of sustainability-focused actions, including reducing food waste production through the reutilization of marine by-products. Furthermore, waste and by-products generated by the seafood industry constitute approximately 20% of total food processing waste (Sharma et al., 2022). The utilization of existing and high-potential by-products and side streams for the production of value-added products aligns with the goals of the circular economy (Zhao et al., 2022). The role of Industry 4.0 technologies in advancing the circular economy to achieve net-zero transitions through efficient waste management has been highlighted recently (Kurniawan et al., 2022). Innovative approaches have been developed to transform low-value fish processing waste into high-value products, including polyunsaturated fatty acids (PUFAs), physiologically important peptides, saccharides, and other bioactive compounds (Al-Hilphy et al., 2019). The global fish oil market is projected to reach approximately USD 3.62 billion by 2030 (Reportlinker, 2024). It has been proposed that this market demand could be met by extracting oil from fish waste, such as viscera (Al-Hilphy et al., 2019). In alignment with the principles of the circular bioeconomy and zero-waste concepts, the isolation and purification of fish oil from fish waste should be strongly promoted. This is because all intermediate products generated during the process can subsequently be transformed into value-added products (Venugopal, 2008).

By 2018, 71 different patents had been registered for the utilization of fishery by-products, 24 of which were related to the food industry (de la Fuente et al., 2020). Additionally, it has been reported that over 200 food products formulated with fish oil are available in Japan (Lobine et al., 2022). Fishmeal and fish oil produced from fish waste (FW) showed steady growth between 2015 and 2020. The global fish oil market was valued at $1.91 billion in 2019 and is projected to reach $2.84 billion by 2027, with a compound annual growth rate (CAGR) of 5.79% from 2021 to 2027. Lipids in FW comprise omega-3 (ω-3) fatty acids, fats, fat-soluble vitamins, squalene, phospholipids, and cholesterol fractions, accounting for 19% to 21% of fish internal organs. Furthermore, fish heads, intestines, and bones are rich sources of fatty acids, particularly oleic, palmitic, linoleic, and eicosenoic acids (Kandyliari et al., 2020; Nam et al., 2019).

Fish skeletons consist of calcium, EPA, DHA, and collagen. Research on sea bream by-products has shown that the head, intestines, and bones are good sources of lipids (Kandyliari et al., 2020).

Fish oil can be obtained from fat-rich tissues such as the skin, liver, head, skeleton, fins, meat, and cavities around the intestines of oily fish, which typically contain 2-30% fat (Joseph et al., 2019; Karkal & Kudre, 2020). The increase in fish oil production is primarily driven by the growing demand for fish oil as a component in aquaculture industries and food formulations (Finco et al., 2017)

Furthermore, fish oil production, especially from fish by-products, presents significant potential for high-quality and high-value markets. The growing global trend in fish product processing has also increased the volume of by-products. In 2016, global fish oil production derived from by-products accounted for 26% of total fish oil production (Jackson & Newton, 2016). In

fisheries and aquaculture industries, liquid and solid fats represent a substantial portion of fish processing waste. Their quantities depend on factors such as the fat content of specific fish species, the distribution of fat across various fish parts, and the age, gender, and nutritional status of the fish (Karkal & Kudre, 2020). For example, it is well established that the internal organ mass of discarded fish contains significant amounts of liquid or solid fats and proteins (Kudre et al., 2017). Fish oil is found in varying quantities in the meat, head, skeleton, fins, tail, skin, and intestines of fish. In fish, oils are typically stored in the subcutaneous tissues beneath the skin, and their quality parameters are comparable to those of commercially edible oils (Šimat et al., 2019). Fish oil is primarily obtained from whole fish or livers. The oil extracted during fishmeal production is used as a raw material for fish oil production (Hardy & Tacon, 2002). However, the oil obtained through this process is of high quality, which increases its cost. As an alternative, by-products have started to be used for the production of environmentally friendly and high-value-added products. Certain fish by-products and discarded species resulting from the processing of oily fish can serve as quality sources of fish oil for human consumption (Aidos et al., 2001; Wu & Becthel, 2008; Rubio-Rodriguez et al., 2012). Another relevant application of oil derived from fish waste is the production of environmentally friendly fuels, particularly biodiesel. Waste oils are potentially advantageous compared to petroleum and unprocessed vegetable oil-based fuels due to their utilization of waste, fuel production, disposal, lower cost (25 cents per gallon for fish oil compared to $1.19 per gallon), and overall reduction in emissions over their lifecycle. Additionally, they possess a calorific value similar to petroleum distillates (Yahyaee et al., 2013). For these reasons, several studies have investigated and confirmed the potential of fish waste oil for biodiesel production. In a study conducted by Martins et al. (2015), the physicochemical properties of fish-based biodiesel derived from tilapia waste oil were evaluated according to the standard requirements established by the Brazilian National Petroleum Agency. The study verified that the obtained biodiesel met the specifications for specific gravity, kinematic viscosity, water content, acidity level, flash point, and oxidative stability. This demonstrated the potential of waste oil from tilapia to serve as a high-quality raw material for biodiesel production. Similar results were achieved through the pyrolysis of waste fish oil, an animal triglyceride source, at 525 °C, confirming the feasibility of producing biofuels with good similarity to petroleum-based fuels (Wisniewski et al., 2010).

The gibel carp (*Carassius gibelio*), commonly referred to as the Israeli carp in Turkey, is acknowledged as an invasive species in the region. It has established large populations and poses a serious threat to local biodiversity through its aggressive competition and efficient reproductive strategies. The gibel carp is highly adaptable in its reproductive strategies, capable of both sexual and asexual reproduction, which facilitates its rapid expansion across various aquatic habitats. As a batch spawner, it can produce between 30,000 and 400,000 eggs per spawning cycle (İlhan et al., 2014; Tarkan et al., 2012; Szczerbowski, 2001). In Turkey, the gibel carp has proliferated significantly since its introduction, especially in freshwater ecosystems, raising worries regarding its effects on indigenous fish species (Parmaksız et al., 2017; Özdilek et al. 2019). The gibel carp ecological importance and limited commercial value across much of its range. In Southwestern Anatolia, it is not regarded as a highly valuable resource and is typically sold locally, primarily as fresh fish kept on ice. Moreover, it is generally not a preferred species in most parts of Turkey (Şaşı and Balık 2003).

In this study, the potential utilization of meat, scales, viscera, and bony structures of the economically insignificant Gibel carp from the Black Sea was investigated as an alternative lipid source for human consumption and as functional products to enhance the nutritional value of animal feed. Applications in various fields such as food, medicine, pharmacology, and cosmetics were also explored. In this context, lipid oxidation analyses were performed based on peroxide value (PV), free fatty acids (FFA), and thiobarbituric acid (TBA) values. The aim was to provide insights into the composition of these waste materials. Consequently, an economically valuable by-product will be derived from Gibel carp (*Carassius gibelio*), a species considered a global issue in fisheries, necessitating preventive measures.

Material and Methods

Samples of gibel carp (*Carassius gibelio*) were collected from fishermen in both the Kızılırmak and Yeşilırmak rivers within the borders of Samsun Province. A total of 46 samples were transported to the Processing Technology Laboratory at Ordu University, Fatsa Faculty of Marine Sciences, in foam boxes with ice (Figure 1 and 2). The fish, with an average weight of 166 g (114–227 g) and an average length of 21 cm (19–23 cm), were sorted based on waste composition and analyzed.

Analyses Conducted on Fish

Lipid Analysis

Lipid analysis was conducted following the method described by Bligh and Dyer (1959). A 15 g homogenized sample was mixed with 120 ml of methanol/chloroform (1:2 ratio) and blended using a Waring blender. Subsequently, 20 ml of 0.4% $CaCl_2$ solution was added to the mixture. The samples were filtered through filter paper (Schleicher & Schuell, 5951/2, 185 mm) and transferred into pre-weighed round-bottom flasks after being dried in an oven at 105 °C for 2 hours. The flasks were sealed to prevent air exposure and stored in a dark

environment overnight. The following day, the methanol-water upper layer was removed using a separatory funnel. The remaining chloroform-lipid layer was evaporated using a rotary evaporator in a water bath at 60 °C to remove the chloroform. The flasks were then placed in an oven at 60 °C for 1 hour to ensure the complete evaporation of the chloroform. After cooling to room temperature in a desiccator, the lipid residue was weighed using a precision balance with a sensitivity of 0.1 mg.

Lipid Content (%)=[Weight of flask (g) + Lipid (g)]-[Weight of flask (g)]x100/Sample amount (g)

Ash Analysis

Porcelain crucibles used for crude ash analysis were first dried in an oven at 103ºC for 2 hours, cooled in a desiccator, and their tare weights were recorded using a precision balance with a sensitivity of 0.1 mg. Homogenized samples weighing 3.3–5 g were placed into the crucibles and incinerated at 550 ºC for 4 hours until the residue turned light gray. After cooling to room temperature in a desiccator, the crucibles were reweighed using the precision balance (AOAC, 1990a). The crude ash percentage of the sample was calculated using the following formula:

Figure 1. Gibel carp (*Carassius gibelio*) samples used in this study.

Figure 2. Fish waste used in this study.

Crude Ash Content (%)=[Weight of crucible (g)+Weight of Crude Ash (g)]-Weight of crucible (g)x100/Sample amount

Moisture Analysis

Moisture analysis was conducted based on the method described by AOAC (1990b). Petri dishes were dried in an oven at 105°C for 1 hour, cooled in a desiccator for 30 minutes, and their tare weights were recorded using a precision balance with a sensitivity of 0.1 mg. Approximately 4–5 g of homogenized samples were placed into the pre-weighed Petri dishes and dried until a constant weight was achieved (approximately 8 hours). Following this, the dishes were placed in a desiccator to cool to room temperature and then weighed using the precision balance. The results were recorded, and the moisture content of the sample was calculated using the following formula:

Moisture content (%)=Initial weight -Final weight x 100/Sample weight (g)

Protein Analysis

The protein content in the hydrolysis solution was determined using the Lowry (1951) to optimize the hydrolysis process. Protein amounts were calculated using a standard calibration curve. Bovine serum albumin was used as the protein standard.

Analyses Conducted on Lipids

Peroxide Value (PV)

To determine the peroxide value, 1 g of lipid sample was dissolved in 20 ml of chloroform. Subsequently, 50 ml of acetic acid: chloroform solution (60:40 ratio) was added, and the mixture was shaken until the lipid was completely dissolved. After dissolving the lipid, 1 ml of saturated potassium iodide was added. The mixture was shaken for approximately 20 seconds, followed by incubation in a dark environment for 30 minutes. Then, 100 ml of distilled water was added, along with a few drops of 1% starch solution. The mixture was heated until a clear color appeared and then titrated with 0.002 M sodium thiosulfate (IUPAC, 1992). The same procedure was conducted for the blank sample without the lipid. The peroxide value was calculated using the formula below**:**

Peroxide value: 2 (C-B)/W meq O_2 /kg

Where, C: Volume of 0.002 M sodium thiosulfate used for the sample (ml).

B: Volume of 0.002 M sodium thiosulfate used for the blank (ml).

W: Weight of the lipid sample (g).

Free Fatty Acid Analysis (FFA)

To determine the free fatty acid (FFA) content, 0.5 g of previously extracted lipid was weighed and neutralized in a diethyl ether: ethanol mixture (25:25 ml ratio). Subsequently, 1 ml of 1% phenolphthalein indicator was added to the mixture. The resulting solution was titrated with 0.1 M sodium hydroxide until a stable pink color persisted for at least 15 seconds, indicating neutralization (Firestone, 1989). The percentage of free fatty acids, expressed as oleic acid, was calculated using the following formula:

% Free Fatty Acid (FFA)=W(C−B) ×2.805

Where, C: Volume of 0.1 M NaOH used for the sample (ml).

B: Volume of 0.1 M NaOH used for the blank (ml).

W: Weight of the lipid sample (g).

2.805: Conversion factor for oleic acid.

Thiobarbituric Acid (TBA) Value

The thiobarbituric acid (TBA) value in trout by-product oil was determined using the method described by AOCS (1998). For the analysis, the oil sample was dissolved in 1-butanol and subsequently mixed with TBA (0.02% in 1-butanol). The mixture was incubated in a thermostatic water bath at 95°C for 2 hours. After incubation, the samples were cooled under running tap water for 10 minutes. Absorbance was measured at 532 nm against a corresponding blank.

For the calibration curve, 0.2 mM 1,1,3,3-tetraethoxypropane prepared in 1-butanol was used as the standard. The TBA value was expressed as mg malondialdehyde (MA) per gram of oil.

Statistical Analysis

Statistical analyses were performed using SPSS 18.0 (SPSS Inc., Chicago, IL, USA). One-way ANOVA was conducted to identify significant differences among the groups, with a significance level defined as $P<0.05$. Tukey's HSD post-hoc test was applied to determine pairwise differences.

Results and Discussion

Meat and Waste Ratios of Gibel Carp (*Carassius gibelio*)

After being caught, the Gibel carp were processed in the laboratory, and non-edible parts were separated and quantified following filleting. The proportional distribution of these components was determined as 46% internal organs, 27% meat, 16% scales, and 11% bony structures (Figure 3). Given that meat accounts for only 27% of the total ratio in the Gibel carp, an invasive and economically insignificant species, the utilization of the remaining 63% as alternative resources is crucial. In

fish waste, by-products typically include heads (9–12%), internal organs (12–18%), skin (1–3%), bones (9–15%), and scales (5%) (FAO, 2014).

Macronutrient Composition of Meat and Waste in Gibel Carp (*Carassius gibelio)*

The highest crude protein content was observed in the scales (21.31%), which was significantly different ($P<0.05$) from all other groups. The lowest protein content was detected in the viscera (1.08%), while bony structures and muscle tissue showed intermediate values, with bony structures having significantly higher protein content than muscle tissue. Regarding lipid content, the internal organs had the highest proportion (22.38%), significantly different from all other groups. Scales and bony structures exhibited similar lipid content, while the lowest value was found in the muscle tissue (1.43%), which was also significantly different from the other groups.

In terms of moisture content, a decreasing trend was observed from the fish meat to the scales. The highest moisture content was recorded in the muscle (80.59%), significantly higher than all other groups, followed by the viscera (73.62%), bony structures (71.83%), and scales (67.31%), each showing significant differences from one another. Ash content, from highest to lowest, was as follows: scales (9.07%), bony structures (7.20%), viscera (3.25%), and muscle tissue (1.27%). Scales and bony structures had significantly higher ash content than viscera and muscle, while muscle had the lowest ash content, significantly different from all other groups (Table 1).

Suvanich et al. (2006) reported that variations in the nutritional composition of catfish, cod, sole, mackerel, and salmon are species-dependent. The highest lipid content was found in mackerel (11.7%), while cod had the lowest lipid content (0.1%). For protein, the highest content was observed in salmon (23.5%), whereas sole had the lowest (14%). Additionally, the moisture content of the five fish species ranged between 69% and 84.6%. In a study by Korkmaz (2018), the lipid content of whiting and anchovy by-products (heads, skeletons, internal organs) was found to be 6.06% and 7.23% (wet weight basis), respectively, with the highest lipid content identified in trout by-products (22.11%). Anchovy by-products had the highest ash content (4.0%), followed by trout (3.06%) and whiting (3.22%). Roslan et al. (2015) determined that tilapia (*Oreochromis niloticus*) by-products contained 14.60% crude protein, 66.57% moisture, 5.50% lipid, and 8.93% ash.

Al-Hilphy et al. (2020) reported the nutritional composition of common carp (*Cyprinus carpio var.*

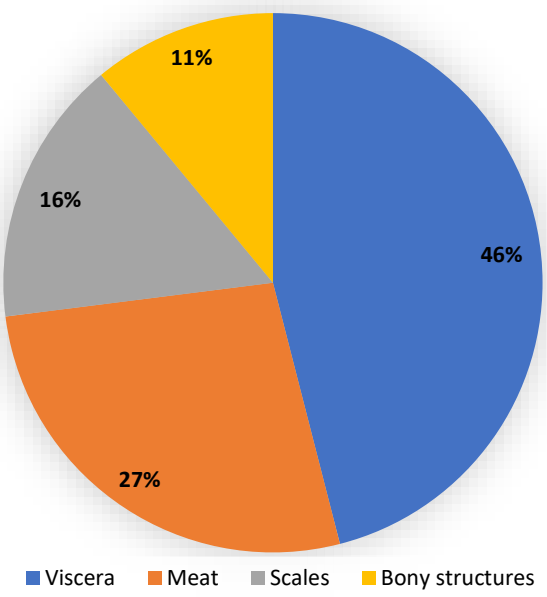

Figure 3. Meat and Waste Ratios of Gibel Carp (*Carassius gibelio*).

Table 1. Macronutrient Composition in Meat and Waste

	Nutritional Contents (%)			
	Crude Protein	Lipids	Crude Ash	Moisture
Meat	14.98±0.08^{c}	1.43±0.06^{c}	1.27±0.28^{d}	80.59±1.71^{a}
Scales	21.31±0.08^{a}	2.31±0.74^{b}	9.07±0.53^{a}	67.31±2.93^{d}
Viscera	1.08±0.08^{d}	22.38±1.58^{a}	3.25±0.91^{c}	73.62±1.58^{b}
Bony structures	18.38±0.08^{b}	2.59±0.17^{b}	7.20±0.77^{b}	71.83±1.82^{c}

Values are expressed as mean ± standard deviation. Different superscript letters (a–d) in the same column indicate significant differences between groups ($P<0.05$) based on one-way ANOVA followed by Tukey's HSD post-hoc test. Total number of sample is 46.

communis) viscera as 63.96%±0.25 moisture, 22.98%±0.09 protein, 12.03%±0.10 fat, and 1.03%±0.05 ash. Saputra and Nurhayati (2016) reported the proximate composition of carp (*Cyprinus carpio*) meat and viscera. The meat contained 76.7%±0.05 moisture, 18.4%±0.04 protein, 3.52%±0.06 fat, and 1.07%±0.01 ash, while the viscera had 76.25%±0.05 moisture, 0.95%±0.04 protein, 1.3%±0.06 fat, and 2.47%±0.04 ash.

The composition of tilapia internal organs has been reported as 14.62% protein, 10.75% lipid, 60.44% moisture, and 4.90±0.61% minerals (Shirahigue et al., 2016). These results are comparable to our findings. As observed in the literature, the chemical composition of fish by-products varies depending on factors such as fish species, body part ratios of the by-products, season, and fish size (Benjakul & Morisey, 1997; Korkmaz & Tokur, 2022a, b). Similarly, the composition of fish oil is primarily influenced by the fish species, the by-product from which the oil is extracted, age, gender, health status, harvesting season, and the extraction method used (Karkal & Kudre, 2020).

Quality Parameters of Oil Extracted from Meat and By-products of Gibel Carp (*Carassius gibelio)*

In general, the highest oxidation values were observed in viscera, while the lowest values were recorded in the scales for peroxide value (PV) and in the meat for free fatty acids (FFA). The highest PV was observed in the internal organs (3.8 meq O_2/kg), while the lowest was in the scales (2.47 meq O_2/kg). FFA values ranged between 3.34% and 8.33%, with the highest value in viscera and the lowest in the meat. For TBA values, the meat, scales, and bony structures showed similar and the lowest levels, whereas the internal organs had the highest value at 0.08 mg MA/kg (Table 2).

Peroxide Value (PV)

The highest peroxide value (PV) was observed in the oil extracted from internal organs (3.8 meq O_2/kg), followed by meat (2.89 meq O_2/kg), oil from bony structures (2.57 meq O_2/kg), and the lowest value in scales (2.47 meq O_2/kg). Statistical analysis revealed significant differences between the groups ($P<0.05$). The viscera, with the highest PV, were significantly different from all other groups, highlighting their greater susceptibility to lipid oxidation due to higher lipid content. Meanwhile, the scales and bony structures showed no significant difference between each other, both exhibiting the lowest PV values.

Özyurt et al. (2018) reported a PV of 2.12 meq O_2/kg for fish oil obtained using acid silage from sea bass by-products. Monsiváis-Alonso et al. (2020) noted a higher PV of 8.65 meq O_2/kg for tuna oil, while Soydan and Erdoğan (2009) found a PV of 3.93 meq O_2/kg in anchovy oil. According to Codex (1999), the acceptable limit for edible oils is 10 meq O_2/kg. EFSA (2010) emphasized that fish oils with PV values between 5 and 10 meq O_2/kg are unsuitable for inclusion in food products. Similarly, GOED (2019) recommended that high-quality fish oil should have a PV below 5 meq O_2/kg.

The PV of crude oils (meq O_2/kg) varies depending on the oil extraction method, the quality of the fish used for extraction, and the storage conditions of the crude oil. Poor processing and storage practices can result in high PV values (>10 meq O_2/kg), indicating oxidative degradation (EFSA, 2010). When evaluating the results of this study, it is evident that all groups remained within acceptable peroxide value limits, suggesting good quality and proper handling of the oils.

Free Fatty Acid (FFA) Analysis

The free fatty acid (FFA) content showed significant differences among the oil samples obtained from various parts of the Gibel carp (*Carassius gibelio*) ($P<0.05$). The lowest FFA value was observed in the oil extracted from the meat (3.34%), while the oil from scales had an FFA value of 3.49%, followed by oil from bony structures at 3.57%. The highest FFA value was recorded in the oil extracted from the internal organs (8.33%), which was significantly different from all other groups. The higher FFA content in viscera results from the activity of natural enzymes present in the viscera (Reece, 1981). Oils from meat, scales, and bony structures did not show significant differences from each other, forming a single statistical group.

Fish oils with high autolytic activity and polyunsaturated fatty acid content are highly prone to lipolysis and oxidation, which often results in high FFA levels (Soldo et al., 2019). FFAs are produced through the hydrolysis of lipids and can affect the organoleptic properties of the oil (Ashton et al., 2002). According to the International Fishmeal and Fish Oil Organisation (IFOMA), the acceptable FFA range for crude fish oil is 1–7% as oleic acid (typically 2–5%) (Bimbo, 1998).

Table 2. Quality Parameters of Oil Extracted from Meat and By-products

	PV (meq O_2/kg)	FFA (%)	TBA (mg MA/kg)
Meat	2.89±0.03^b	3.34±0.04^b	0.05±0.08^a
Scales	2.47±0.39^c	3.49±0.23^b	0.05±0.01^a
Viscera	3.80±0.04^a	8.33±0.03^a	0.08±0.02^b
Bony structures	2.57±0.25^c	3.57±0.37^b	0.05±0.01^a

Values are expressed as mean ± standard deviation. Different superscript letters (a–c) within the same column indicate significant differences between groups ($P<0.05$), as determined by one-way ANOVA followed by Tukey's HSD post-hoc test.

However, it is generally recommended that edible oils have FFA values below 3% (Özyurt et al., 2013; Soldo et al., 2019).

Differences in FFA values in fish oils are influenced by the freshness of the fish and by-products used, storage conditions, extraction methods, and refining stages. García-Moreno et al. (2014) reported lower FFA values in oils extracted at temperatures above 45 °C, likely due to lipase deactivation. Soldo et al. (2019) observed a reduction in FFA values during the deodorization and neutralization stages of crude fish oil refining. Abd El-Rahman et al. (2018) mentioned that tilapia internal organ oil contained 3% FFA, while Suseno et al. (2015) found FFA values ranging between 3.85% and 7.15% in oils extracted from tilapia. Monsiváis-Alonso et al. (2020) reported an FFA value of 7.07% in tuna oil. Crexi et al. (2010) reported the free fatty acid (FFA) content in crude oil of carp (*Cyprinus carpio*) as 3.35±0.02%. Through refinement processes, the FFA content was reduced to 5.31±0.02% after degumming, 0.56±0.02% after neutralization, 0.45±0.02% after bleaching, 0.47±0.02% after winterization, and finally to 0.08±0.01% after deodorization, These findings are comparable to our results

Thiobarbituric Acid (TBA) Value

The TBA values showed significant differences ($P<0.05$) among the oils extracted from different parts of the Gibel carp (*Carassius gibelio*). The lowest TBA values were observed in the oils extracted from meat, scales, and bony structures (0.05 mg MA/kg), which were statistically similar to each other. In contrast, the oil from internal organs exhibited the highest TBA value (0.08 mg MA/kg), which was significantly different from the other groups.

The TBA value represents malondialdehyde (MDA), a secondary oxidation product, and serves as a key indicator of rancidity in oils. It is reported that TBA values exceeding 19 mmol MDA per 1000 g of fish oil indicate that the product is beyond acceptable limits (Kaitaranta, 1992). For comparison, Wang et al. (2022) reported a TBA value of 1.4 mg MDA/kg in golden pompano oil, while Albendea et al. (2023) found TBA values of up to 0.4 mg MDA/kg in fish oil. Özyurt et al. (2018) observed TBA values of 1.07 mg MA/kg in fish oil obtained from sea bass by-products using acid silage and bacterial fermentation techniques.

In a study conducted by Crexi et al. (2010), carp (*Cyprinus carpio*) oil was extracted from viscera using fishmeal processing methods, including grinding, cooking, screening, and centrifugation. The study highlighted that TBA values in crude oil can be relatively high depending on processing conditions, with an initial value of 6.7±0.1 mg MA/kg. However, refinement steps such as degumming and neutralization effectively reduced the TBA values to 5.6±0.1 mg MA/kg and 3.2±0.1 mg MA/kg, respectively, improving oil quality.

The TBA analysis tracks secondary oxidation products, particularly aldehydes, making it one of the most important techniques for evaluating the oxidation levels of oils containing unsaturated fatty acids (Schormüller, 1969). According to Schormüller, TBA values in good-quality materials should be below 3 mg MA/kg. Based on this criterion, all oil samples in our study remained well within acceptable TBA limits. The observed differences emphasize the greater susceptibility of internal organ oil to secondary lipid oxidation, likely due to higher levels of polyunsaturated fatty acids, whereas oils from meat, scales, and bony structures showed better oxidative stability.

Conclusion

The results of this study aim to contribute to the development of an academic foundation for the commercialization of a raw materials that can meet the needs of various industries, particularly the food sector. Utilizing fish processing by-products for fish oil production is critical for sustainable aquaculture practices. The reuse of fish waste generated by the fisheries industry holds significant potential to positively impact various sustainable development goals by enabling the production of value-added products. This, in turn, supports waste valorization and contributes to the circular economy by reducing solid waste.

The recovery and utilization of food waste have become a priority, especially in developed countries, where by-products generated during food processing are increasingly recognized for their potential. These by-products, rich in protein, carbohydrates, and lipids, offer a valuable resource for the development of functional products. The effective evaluation of these by-products can provide significant economic benefits at an industrial scale, garnering considerable interest from researchers and the food industry.

Based on the findings of this study, the quality parameters of the Gibel carp (*Carassius gibelio*) meat and by-products are generally within acceptable limits. This suggests that, in addition to the fish meat itself, the by-products of Gibel carp can be considered as alternative raw materials for various applications. Such an approach not only supports scientific advancements but also offers economic benefits by transforming waste into valuable resources, contributing to sustainability and the broader goals of the circular economy.

Ethical Statement

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Author Contribution

Korkmaz, K.: Conceptual idea, methodology design, data collection, data analysis and interpretation, writing-original draft.

Tokur, B.: Methodology design, writing-review and editing, supervision, conceptual idea

Bilgin Fıçıcılar, B.: Writing-review and editing, data analysis and interpretation,

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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