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Proximate composition and colour values of muscle tissue of male and female blunt-snouted mullet (*Mullus ponticus* Essipov, 1927) from Black Sea

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A B S T R A C T

In the Mediterranean and Black Sea, red mullet is a fish species of significant commercial value. It usually inhabits sandy and muddy bottoms in the Eastern Atlantic and Mediterranean basins, which include the Black Sea. Red mullet is subject to high fishing pressure from bottom trawling and small-scale fisheries, making it one of the most valuable bottom fish in the Mediterranean. It's also one of the primary species that bottom trawls catch for commercial purposes. Red mullet's distinct habitat requirements and sensitivity to environmental changes make it a commercially valuable species in the Mediterranean and Black Seas. Its high economic value and ecological importance make it an important focus of research and fisheries management efforts. The objective of this research was to ascertain the nutritional makeup and muscle tissue colour values of red mullet, both male and female, that were collected using bottom gillnets at Sinop, a Black Sea coastal city in the south. In this study, crude protein, crude fat, crude ash, moisture, carbohydrate, and energy values in female blunt-snouted mullet were found as 18.81%, 9.51%, 1.29%, 69.74%, 0.66%, and 199.14 Kcal/100 g. In male red mullet, crude protein, crude fat, crude ash, moisture, carbohydrate, and energy values were determined as 19.06%, 10.07%, 1.16%, 68.97%, 0.73%, and 206.20 Kcal/100 g. Colour analysis is an important finding in distinguishing females and males in various fish species and in understanding sexual dimorphism. It was found that female red mullets were more reddish and yellowish than male red mullets.

INTRODUCTION

Known by most as just "red mullet," this species of benthic fish inhabits the Northeast Atlantic and Mediterranean regions. It inhabits gravelly, sandy, and muddy bottoms up to 500 m deep on the continental shelf (Rodríguez-Romeu et al., 2020). Blunt-snouted mullet is one of the species that industrial bottom trawling targets, but it's also one of the species that's heavily caught using bottom gillnets, the most crucial fishing tool for small-scale fisheries (Özdemir and Erdem, 2011; Aksu et al., 2011; Özdemir et al., 2021). In Turkish seas; the Mullidae family is known to have two genera (*Mullus* and *Upenus*) and four species (*Mullus barbatus*, *Mullus surmuletus*, *Upeneus moluccensis*, and *Upeneus pori*) (Mater et al., 2003; Bat et al., 2008; Gündoğdu and Baylan, 2016). Blunt-snouted mullet (*Mullus ponticus*) is a subspecies specific to the Black Sea (Echreshavi et al., 2022; Fricke et al., 2024; Froese and Pauly, 2024).

The effects of climate change due to global warming, which is seen in all oceans and seas, are also felt in the Black Sea basin (Bat et al., 2007). Accordingly, the stock structures, population characteristics, reproduction time, reproduction areas and feeding behaviors of pelagic and demersal fish species in the Black Sea may also differ. Some changes in the growth and first reproduction lengths of red mullet, one of the important demersal fish of the Black Sea, are remarkable. It is thought that all these factors and changes related to parameters may also affect the food composition of fish.

Red mullet feed on crustaceans, polychaete, and bivalves, and stable isotope analysis has revealed differences in diet and size-related trophic levels among sympatric fish species (Bautista-Vega et al., 2008).

The nutritional composition of red mullet, commonly known as red mullet, has been a subject of scientific research. Studies have emphasized seasonal changes in fat and fatty acids, and it has been discovered that this species is good for human diet and that its muscle lipids are rich in docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) (Özoğul et al., 2011, Duyar and Bayraklı, 2023). It has also been found that the fatty acid composition of red mullet shows seasonal variation, which is affected by changes in water temperature and nutrient availability, affecting fish muscle quality (Polat et al., 2008). Furthermore, research comparing the effects of conventional and green extraction techniques on fish species' fatty acid profiles and lipid yield has demonstrated the high nutritional value of fish, which includes high levels of protein, vitamin, mineral, and lipid content (Özoğul et al., 2011). These findings underline the nutritional importance of red mullet in human nutrition, especially as a source of essential fatty acids and high-quality protein.

Blunt-snouted mullet has been a subject of interest in the Black Sea due to its nutritional composition, economic importance, and high consumption. Various studies have focused on the proximate composition, heavy metal concentrations, fatty acid profiles, and genetic differentiation of blunt-snouted mullet. Roncarati et al. (2012) and Duyar et al. (2023) investigated the proximate composition or heterogeneous profile of red mullet, emphasizing its importance as a widely consumed species in the European Union.

Based on the given references, the L*, a*, and b* values obtained from colour analysis in red mullet species can be attributed to various factors such as sex, nutrition, and regional and seasonal differences. Also, Corsi et al. (2002) monitored a marine coastal area using red mullet as a biological indicator, which can provide valuable information on colour changes due to regional and seasonal differences. Prazdnikov's (2016) study on karyology of red mullet provides genetic information that can be associated with colour differences and regional differences in the species. Kokokiris et al. (2014) study on oocyte development and spawning season of red mullet can provide valuable information on colour differences due to sex in the species.

Determination of L*, a*, and b* values in commercial fish species is very important for understanding sex-related colour differences and their potential implications for future studies. The study revealed statistically significant differences in a* and b* values between female and male individuals, suggesting that these values can be used as markers for sex discrimination (Bergero et al., 2019). In addition, the ability to distinguish between female and male colours in various teleost fish species highlights the importance of colour analysis in understanding sexual dimorphism (Kottler and Schartl, 2018). The use of colour analysis to highlight sex differences in fish species is supported by the literature on sexual dimorphism and colour discrimination in various fish species. The findings of the study contribute to the increasing knowledge on the role of colour in sex recognition and discrimination in fish, providing valuable information for future research in this area.

MATERIALS AND METHODS

The Black Sea coasts of Sinop were the study's location. The Sinop region is very important for small scale fisheries. Sinop region is three fisheries areas such as İnceburun region, outer harbour, and inner harbour region. Fishermen have been captured, especially whiting and blunt-snouted mullet, during all fishing seasons (Figure 1).

Red mullet samples were captured by set nets (gillnets and trammel nets) between 15 April 2022 and 31 August 2022. Nets have monofilament and multifilament material. The mesh sizes of gillnets and trammel nets were 32, 36, and 40 mm. Depth ranges used of set nets were between 15 m and 45 m.

Figure 1. The chart of the fish sampling area (İnceburun, outer harbour, and inner harbour)

Captured fish samples were placed in iced polystyrene boxes and brought to the laboratory, and proximate composition analyses were performed immediately. The total length and weight of all samples were measured as 1 mm and 0.001 g. Gender analyses of fish were performed macroscopically in the laboratory (Figure 2).

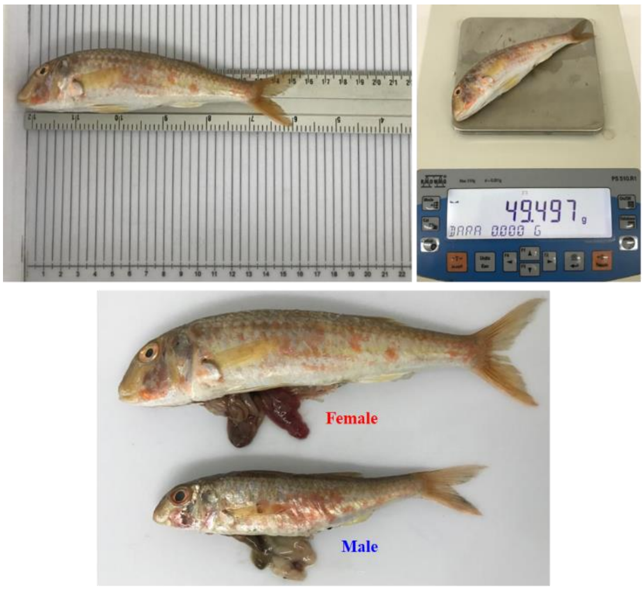

Figure 2. Male and female fish samples

The muscle tissue of the fish was taken and homogenized. Three parallels and two replications were used to analyze the nutritional of fresh red mullet. Nutritional composition analysis results are given in Table 2. From nutrient composition analysis, total crude protein was performed using Kjeldahl (AOAC, 1990), crude fat analysis (Bling and Dyer, 1959), crude ash analysis (AOAC, 1984), and moisture analysis (Ludorf and Meyer, 1973). Carbohydrate and energy amounts were calculated according to Merril and Watt (1973) using the following equations (Eqs. 1-2).

Colour measurements were determined using Konica Minolta/CR-A33a (Tokyo, JP) apparatus and CR-400 brand/model device with "Commission Internationale de l'Eclairage" (CIE) coordinate system parameters. The instrument was calibrated with black and white standard plates before the analysis. The Commission Internationale de l'Eclairage (CIE)-Lab L*, a*, and b* scores were obtained, which showed lightness, redness (+)/(-) greenness, and yellowness (+)/(-) blueness, respectively. Chroma and hue angle were also calculated using the following formulas (Eqs. 3-4) (CIE, 1976).

RESULTS

A total of 25 kg of blunt-snouted mullet was caught during this study. In this study, biometric data and the nutritional composition of female and male blunt-snouted mullet were investigated, and the results are given in Table 1.

$$Carbohydrate\ (g/100g) = 100 - (moisture + Fat + Protein + Ash \quad (1)$$

$$Energy\ (Kcal/100g) = (Fat * 9.50) + (Protein * 5.65) + (Carbohydrate * 3.90) \quad (2)$$

$$C *= \sqrt{a *^2 + b *^2} \quad (3)$$

$$h *= tan^{-1}(b */a *) \quad (4)$$

Table 1. Biometric data and nutritional composition of red mullet

Parameters		Gender	Mean and Standard Errors
Biometric Data	Total Length (cm)	♂	14.51±0.090
		♀	16.69±0.080
	Weight (g)	♂	35.52±0.89
		♀	44.41±0.64
Proximate Composition	Moisture (%)	♂	68.974±0.106
		♀	69.741±0.375
	Crude Protein (%)	♂	19.060±0.030
		♀	18.809±0.146
	Crude Fat (%)	♂	10.070±0.348
		♀	9.507±0.050
	Crude Ash (%)	♂	1.169±0.071
		♀	1.288±0.048
	Carbohydrate (%)	♂	0.731±0.004
		♀	0.655±0.002
	Energy (Kcal/100g)	♂	206.201±0.110
		♀	199.142±0.090

Table 2. Colour findings of male and female blunt-snouted mullet.

Groups	Parameters						
	L*	a*	b*	h*	C*	WI	YI
♂	56.23±0.40^{a}	2.39±0.23^{b}	0.18±0.07^{b}	4.18±1.27^{b}	2.14±0.02^{b}	55.52±0.41^{a}	0.46±0.18^{b}
♀	56.82±0.66^{a}	6.69±0.30^{a}	5.17±0.35^{a}	37.61±0.92^{a}	8.46±0.44^{a}	55.99±0.64^{a}	12.99±0.84^{a}

Note: L* brightness/whiteness, a* redness/greenness, b* yellowness/blueness, h* hue angle (°), C* Chroma, WI whiteness index, YI yellowness index.

The colour parameters L*, a*, b*, h*, C*, whiteness index (WI), and yellowness index (YI) are essential in assessing the colouration of fish, which significantly influences consumer preferences and market value. The L* parameter indicates lightness, ranging from 0 (black) to 100 (white), while the a* and b* parameters represent colour dimensions where a* indicates the red-green axis and b* indicates the yellow-blue axis (Hajipour and Shams-Nateri, 2016; Ismail and Kocabay, 2018). The chroma (C*) is derived from the a* and b* values, reflecting the intensity of colour, and the hue angle (h*) describes the specific colour type (Conner and MacLean, 2013; Hajipour and Shams-Nateri, 2016). Furthermore, the whiteness index (WI) and yellowness index (YI) are critical for evaluating the visual appeal of fish products, as they quantify the degree of whiteness and yellowness, respectively, which can be influenced by factors such as lipid oxidation during storage (Li et al., 2022). These parameters are not only vital for quality control in fish processing but also serve as indicators of freshness and overall product quality, making them indispensable in the seafood industry (Liao et al., 2021). Table 2 displays the colour analysis results for the male and female blunt-snouted mullet used in this study.

The parameters such as chroma (C*), hue angle (h*), whitening index (WI), and yellowing index (YI) are determined by the L*, a*, and b*, which are the main components of the CIE colour coordinate system (Bekhit et al., 2018).

DISCUSSION

The moisture content of blunt-snouted mullet is an important aspect of its overall proximate composition, which influences its quality and shelf life. Studies have shown that the moisture content in blunt-snouted mullet can vary significantly depending on factors such as season, environmental conditions, and the fish's diet.

Male blunt-snouted mullet had a moisture content that was lower (68.97%) than female blunt-snouted mullet (69.74%), but there was no statistically significant difference between the two (p>0.05). Polat et al. (2008) found the moisture content of red mullet as 73.84% in their study. Tulgar and Berik found the moisture content of red mullet as 72.17% in spring in their study in 2012. Research indicates that the moisture content of red mullet typically ranges from approximately 70% to 80% of its total weight (Roncarati et al., 2012). For instance, moisture content in red mullet muscle significantly decreased during the spring season, which correlated with an increase in protein content. This inverse relationship between moisture and protein content suggests that as the fish accumulates protein reserves, particularly in preparation for spawning, the moisture content tends to decline (Polat et al., 2008).

Moreover, the proximate composition of red mullet has been documented to reflect its feeding habits. The fish primarily consumes benthic organisms, which may influence its moisture content due to variations in dietary intake (Roncarati et al., 2012). Additionally, environmental factors such as water temperature and salinity can also affect the moisture levels in red mullet, as these factors influence the fish's metabolic processes and overall health (Bouzgarrou et al., 2015).

The moisture content is crucial for determining the quality and shelf life of red mullet. Higher moisture levels can lead to a shorter shelf life due to increased susceptibility to microbial growth and spoilage (Bouzgarrou et al., 2015). Therefore, understanding the moisture content is essential for both consumers and fishery management to ensure the quality and safety of this commercially important species.

The average crude protein content of male blunt-snouted mullet in the Black Sea was determined as 19.06% (Çiloğlu and Akgümüş, 2019). In this study, the protein content of male and female blunt-snouted mullet was determined as 19.06% and 18.81%, respectively. Although the amount of protein in females is slightly less, there is no statistical difference between the sexes (p>0.05).

Because of the potential effects on nutrition and fisheries management, red mullet protein content is a topic of great interest. Research has indicated that a number of factors, such as seasonal variations and environmental circumstances, can have a substantial impact on the protein content of red mullet. Specifically, Polat et al. (2008) found that protein levels in red mullet muscle significantly increased during spring, correlating with a decrease in moisture content, suggesting an inverse relationship between these two parameters. This seasonal variation is likely influenced by the abundance of food sources available to the fish, which affects their growth and nutritional composition (Polat et al., 2008).

Moreover, the proximate composition of red mullet has been documented to reflect its dietary habits. The fish primarily feed on crustaceans and polychaetes, which are rich in monounsaturated fatty acids but low in DHA (decosahexaenoic acid) (Roncarati et al., 2012). This dietary preference not only influences the fatty acid profile but also the overall nutritional value of the fish, including its protein content. For instance, the lipid content in red mullet has been reported to be higher than in some other fish species, which may also affect the protein-to-fat ratio (Tufan et al., 2018).

A comparative study of several fish species showed that red mullet's protein content is competitive with that of other economically significant fish, underscoring the fish's worth in the seafood industry. The protein content of red mullet is particularly significant for culinary applications, as it is a popular choice in Mediterranean cuisine, where it is valued for both its flavor and nutritional benefits (Biandolino et al., 2023).

In summary, the protein content of red mullet is influenced by seasonal variations, dietary habits, and environmental conditions, with reported values ranging from 14.54% to 20.26%. This makes red mullet a nutritionally valuable species in both ecological and culinary contexts.

More research needs to be done on this fish species to understand whether the meat of male and female blunt-snouted mullet living in the Black Sea differs in terms of crude protein content.

The fat content blunt-snouted mullet is a significant aspect of its nutritional profile, influencing both its culinary applications and its role in the diet of consumers. The lipid content of blunt-snouted mullet varies based on several factors, including seasonal changes, environmental conditions, and geographical location.

The crude fat contents in the meat of male and female blunt-snouted mullet in the current study were found to be 10.7% and 9.51%, respectively. Comparing results with other studies requires accounting for the differences in fat content across different species. Studies on the proximate composition of fish species have shown various levels of fat content. For example, a study on the fatty acid profile of various fish species reported a lipid content of 7.0% in red mullet (Roncarati et al. 2012). This suggests that the fat content of blunt-snouted mullet from the Black Sea is within the range observed in other fish species.

Research indicates that the crude fat content of blunt-snouted mullet can range significantly, with values reported between 3.68% and 5.76% depending on the specific conditions under which the fish were caught (Polat et al., 2008). For instance, Tufan et al. noted that blunt-snouted mullet caught from the Black Sea exhibited higher fat contents compared to other fish species, suggesting that environmental factors and feeding habits play a crucial role in determining lipid levels (Tufan et al., 2018). The lipid content is particularly influenced by the fish's diet, which primarily consists of benthic organisms such as crustaceans and polychaetes, known to be rich in essential fatty acids (Lloret et al., 2007).

Furthermore, the lipid reserves in red mullet are particularly important during pre-spawning periods, as they provide the necessary energy for reproductive activities. This seasonal accumulation of lipids may also explain the variations in fat content observed in different studies as fish prepare for spawning by increasing their fat reserves (Lloret et al., 2007).

In conclusion, the fat content of blunt-snouted mullet is variable, influenced by environmental factors, dietary habits, and seasonal changes. The lipid content ranges from approximately 1.26% to 18.12%, with significant implications for its nutritional profile and culinary uses. All things considered, more research taking into account processing techniques, gender effects, and species-specific variations is needed to provide a thorough comparison of fat content in different species, even though the fat content of male and female blunt-snouted mullet in the Black Sea is consistent with findings from other fish species.

The meat of blunt-snouted mullet inhabiting the Black Sea, both male and female, had crude ash contents of 1.17% and 1.29%, respectively. The gender differences were not statistically different ($p>0.05$). The crude ash content of blunt-snouted mullet let is an important parameter in assessing its nutritional and mineral composition. Ash content generally reflects the total mineral content of the fish, which can vary based on several factors, including diet, habitat, and environmental conditions.

Research indicates that the ash content in blunt-snouted mullet can be influenced by its feeding habits and the types of prey available in its habitat. For instance, polychaetes, which are known to be high in EPA and monounsaturated fatty acids but low in DHA, are the main food source for red mullets (Roncarati et al., 2012). This dietary preference can affect the overall mineral composition and, consequently, the ash content of the fish. In a study examining the mineral composition of various fish species, including red mullet, it was found that the ash content is a significant indicator of the mineral levels present in the fish, which can range widely depending on environmental factors and dietary intake (Özden et al., 2009).

Moreover, the ash content can also be influenced by the fish's exposure to heavy metals and pollutants, as red mullets are benthic feeders that come into contact with sediments where such contaminants may accumulate (Ozuni et al., 2022). This exposure can lead to increased levels of certain trace metals in the fish, which would subsequently reflect in the ash content. For example, studies have shown that red mullet from contaminated areas exhibited higher concentrations of heavy metals, indicating a potential increase in ash content due to the accumulation of these minerals (Küçüksezgin et al., 2001).

As for precise values, related studies on related species indicate that the ash content in red mullet usually varies from 1% to 3% of the total body weight, based on various factors including the fish's age, size, and environmental conditions. However, direct measurements of ash content in red mullet are not well documented in the literature (Abo-Taleb et al., 2021). Furthermore, the overall nutritional profile, including ash content, can vary seasonally, with some studies indicating that the nutritional composition, including protein and fat levels, can change significantly throughout the year, which may also affect ash content indirectly (Maravelias et al., 2006).

In conclusion, the ash content of blunt-snouted mullet is a multifaceted characteristic influenced by dietary habits, environmental conditions, and exposure to pollutants. While specific quantitative data may be limited, the general understanding of its mineral composition can be derived from related studies on fish nutrition and environmental impacts.

In this study, the carbohydrate content of male and female red mullets was found to be 0.73% and 0.66%, respectively. Fish's carbohydrate content varies greatly depending on a number of characteristics, such as species, sex, age, and environmental conditions.

The study by Lahnsteiner (2006) provides insights into the carbohydrate metabolism of red mullet, indicating that the carbohydrate levels in the fish are influenced by developmental stages, particularly during the vitellogenic phase of egg development. This suggests that the carbohydrate content may fluctuate based on reproductive status, which could explain some variability in your measurements. Furthermore, Koubaa et al. (2010) examined the chemical compositions of a number of fish species, such as red mullet, noting that moisture and nutrient content can differ significantly among species and even within the same species depending on their physiological state. These findings are consistent with our own study, and it's possible that the fish's sampling environment had an impact on the carbohydrate levels we saw.

Moreover, Soliman et al. (2017) highlighted those dietary habits, particularly the consumption of crustaceans and polychaetes, can influence the biochemical composition of red mullet. This dietary influence could account for the differences in carbohydrate content observed between sexes, as males and females may exhibit different feeding behaviors or preferences, potentially leading to variations in their nutritional profiles. The findings of Aguirre and Sánchez (2005) further support this notion, as they discuss resource partitioning between red mullet and other species, which could imply that dietary differences might also contribute to the observed carbohydrate levels.

Additionally, the research by Girolametti et al. (2022) on mercury content in red mullet suggest that environmental factors, including pollution levels, can affect the overall health and biochemical composition of fish. This environmental influence could also extend to carbohydrates metabolism, potentially explaining the differences in carbohydrate levels between male and female specimens.

In summary, the carbohydrate values you found as 0.73% in males and 0.66% in females are consistent with the existing literature emphasizing the influence of developmental stage, feeding habits and environmental conditions on the biochemical composition of red mullet. The variations in carbohydrate content between sexes may reflect underlying physiological differences or environmental adaptations, warranting further investigation into the factors influencing these nutritional metrics.

The energy content of fish muscle, typically expressed in kilos per 100 grams, varies significantly among species and is influenced by factors such as fat, protein, and carbohydrate composition. Fish muscle is predominantly composed of protein, which contributes to its nutritional value, but the total caloric density is mostly dependent on the fat content. For instance, fat provides approximately 9 kcal per gram, compared to 4 kcal per gram for protein (Raesen et al., 2017).

In this research, the energy amounts of male and female blunt-snouted mullet were found to be 206,20 (Kcal/100g) and 199,14 (Kcal/100g), respectively.

Numerous factors, such as the composition of fatty acids and metabolic processes, can have an impact on the energy content of fish muscle. For instance, Nordgarden et al. (2003) highlighted that the metabolism of Atlantic salmon involves significant β-oxidation of monounsaturated fatty acids

(MUFA), which are preferred energy substrates, indicating that energy utilization in fish muscles is closely tied to their lipid composition (Nordgarden et al., 2003). This suggests that energy values in red mullet may similarly be influenced by fatty acid profiles, and further research is warranted.

Moreover, the differences in energy storage between sexes have been explored in various species. O'Connor et al. (2012) noted that hepatic glycogen and muscle lipid content serve as measures of stored energy, which can vary based on sex and reproductive status. This aligns with the findings in red mullet, where the energy content may reflect the physiological demands placed on each sex, particularly during reproductive periods. In many fish species, females often prioritize somatic growth over reproductive investment until they reach maturity, which can affect their energy reserves (Buchtová et al., 2006).

Moreover, the energy content of fish is not static; it can fluctuate based on seasonal changes and the fish's life stage, as well as its feeding habits and metabolic rates. For example, the caloric density of Pacific salmon has been closely linked to lipid content, with larger fish generally exhibiting higher energy values due to their greater mass and fat reserves (O'Neill et al., 2014). This variability underscores the complexity of assessing the energy content in fish muscle and the necessity of considering multiple factors that contribute to its nutritional profile.

The colouration of male and female red mullet is indeed differ, and this difference can be quantitatively assessed using colour parameters such as L*, a*, b*, hue, and chroma (Figure 3). These parameters are part of the CIELAB colour space, which provides a systematic way to describe colour in terms of lightness (L*), red-green chromaticity (a*), and yellow-blue chromaticity (b*) (Park, 2023; Ruan and Wang, 2023).

When it comes to colour analysis, pollution and habitat conditions are only two examples of the environmental elements that might have an impact on the pigmentation of red mullet. Studies have identified the red mullet as a bioindicator species for coastal pollution, where the colour of living fish can reflect the health of its habitat. Exposure to environmental heavy metals and polycyclic aromatic hydrocarbons (PAHs) in particular can change fish metabolic markers (Porte et al., 2002; Conti et al., 2012). Assessment of these pollutants has shown that red mullet accumulates these substances, which can alter its physiological and possibly chromatic characteristics (Lionetto et al., 2001).

Moreover, a great deal of research has been done on the reproductive biology of red mullet, and it has come to light that age, development, and maturity may all have an impact on pigmentation. For example, the size and maturity of the fish are associated with changes in pigmentation that may serve as a visual cue during mating seasons (Kokokiris et al., 2014; Carbonara et al., 2015). Histological analysis of gonadal maturation shows that the reproductive cycle of red mullet is closely linked to environmental conditions, which may also affect its colouration in different seasons (Balcı and Aktop, 2019).

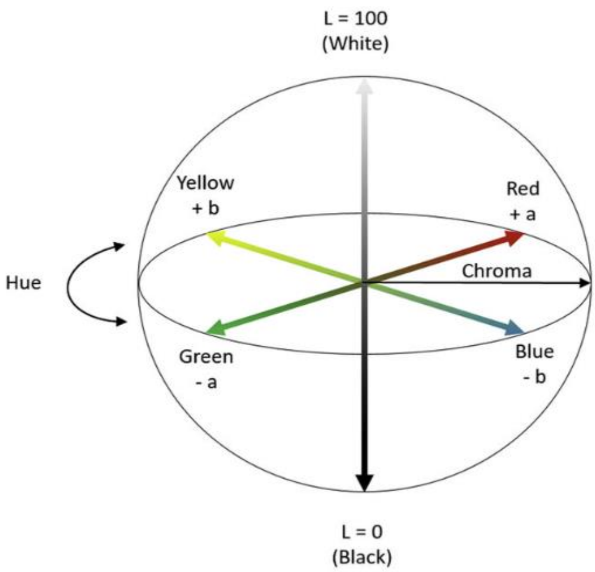

Figure 3. Colour diagram

In this study, the L* value, representing brightness-whiteness, was found to be 56.23 and 56.82 in male and female individuals, respectively. Between the sexes, there is no statistically significant difference ($p>0.05$). The a* value, which represents the red-green axis, was measured as 2.39 and 6.69 in male and female red mull blunt-snouted mullet, respectively. According to this result, female fish are reddish compared to male fish, while male red mullets were lower reddish, closer to green. The b* value, which shows colour distinction in the yellow-blue axis, was found to be 0.18 and 5.17 in male and female red mullet, respectively. Female blunt-snouted mullets were found to be more yellow, while male blunt-snouted mullets were found to be more bluish yellow than females.

Considered a qualitative property of colour, h* is the property by which colours such as redness or greenness are traditionally defined. It defines the variation of a particular colour compared to grey tones in the same range (O'Sullivan et al., 2003). This property is associated with absorbance differences at various wavelengths. The mathematical expression of the h* spectral range in colourimeters corresponds to 0/360, 90, 180, and 270° for redness, yellowness, greenness, and blueness, respectively (Škrlep and Čandek-Potokar, 2007). C*, which represents the quantitative property of chromaticity, is used to measure how much the h* parameter deviates from grey tones in the same range. As the C* value increases, the colour intensity perceived by humans also increases, indicating more vividness and saturation in the appearance of the food (Pathare et al., 2013). WI combines brightness and yellow-blue colours into a single component, expressing the attractive whiteness that is an important determinant in consumers' decision to purchase the product (Škrlep and Čandek-Potokar, 2007). One of the most characteristic features of WI is that it perfectly reveals the whiteness/brightness change caused by the dehydration/drying of the food. YI indicates the degree of yellowing and is widely used to determine conditions such as contamination and oxidation with a single indicator (Pathare et al., 2013). High or low L*, a*, b*, C*, h*, WI, and YI values used in colour analysis have various meanings.

L* (lightness value); when high, it indicates that the sample is lighter, i.e., brighter or whiter, while when low, it indicates that the sample is darker.

a* (Redness/Greenness); It shows that it has more red tones when it is high and more green tones when it is low.

b* (Yellowness/Blueness); when high, it indicates that it has more yellow tones, while when low, it indicates that it has more blue tones.

C* (Chroma); when it is high, the colour is more saturated and vibrant. when it is low, the colour is duller.

h* (Hue Angle Value); either greenish or yellowish. When it is low, the colour is either blue or reddish.

WI (Whiteness Index); A high value suggests that the sample is closer to being white. A low value suggests that the sample is either more colourful or less white.

YI (Yellowness Index), A high value denotes greater yellowness in the sample, whereas a low value denotes less yellowness, or bluishness or whiteness.

These values are often important in terms of product quality, freshness, and consumer perception. For example, a brighter and whiter colour can be an indicator of freshness in foods such as fish. Chroma (C*), hue angle (h*), whiteness index (WI), and yellowing index (YI) parameters are determined by L*, a*, and b* parameters, which are the main components of the CIE colour coordinate system (Pathare et al., 2013). h*, which is considered a qualitative property of colour, is the property by which colours such as redness or greenness are traditionally defined. It defines the variation of a certain colour compared to grey tones in the same range (O'Sullivan et al., 2003). This property is associated with absorbance differences at various wavelengths. The mathematical expression of the h* spectral range in colourimeters corresponds to 0/360, 90, 180, and 270° for redness, yellowness, greenness, and blueness, respectively (Škrlep and Čandek-Potokar, 2007). C*, which represents the quantitative property of chromaticity, is used to measure how much the h* parameter deviates from grey tones in the same range. As the C* value increases, the colour intensity perceived by humans also increases, indicating more vividness and saturation in the appearance of the food (Pathare et al., 2013). WI combines brightness and yellow-blue colours into a single component, expressing the attractive whiteness that is an important determinant in consumers' decision to purchase the product (Škrlep and Čandek-Potokar, 2007). One of the most distinguishing qualities of WI is that it perfectly reveals the whiteness/brightness change caused by the dehydration/drying of the food. YI indicates the degree of yellowing and is widely used to determine conditions such as contamination and oxidation with a single indicator (Pathare et al., 2013). Gümüş (2021) determined the L*, a*, and b* parameters in red mullet (*M. barbatus*) as 68.29; 6.99, and 12.74, respectively. Male and female red mullets do exhibit differences in colouration, with females typically being more colourful and larger than males. Environmental variables also have an impact on these disparities in addition to genetic ones, which can affect the overall appearance and reproductive success of both sexes.

In studies examining sexual dimorphism in fish, it has been noted that female red mullets often exhibit brighter and more vibrant colours compared to males. In order to attract males, females may exhibit heightened colouring during the time of breeding, which makes this especially clear (Sieli et al., 2011). The a* value, representing the red-green axis, may also show higher positive values in females, indicating a greater presence of red hues, while males may have more subdued colours with lower a* values (Choubert, 2010; Ruan and Wang, 2023).

Chroma, which measures colour intensity, is another critical factor in distinguishing between the sexes. Females typically have higher chroma values, indicating a more intense colour saturation, while males may present with lower chroma values, reflecting a more muted appearance (Chajra et al., 2015; Calnan et al., 2017). The hue angle, which describes the type of colour, can also vary between sexes, with females often showing hues that are more appealing during mating displays (Choubert, 2010; Ruan and Wang, 2023).

Environmental factors can also influence these colour parameters. For instance, the availability of carotenoids in their diet can affect the pigmentation in red mullet, leading to variations in L*, a*, and b* values depending on the season and habitat conditions (Choubert, 2010; Pustina-Krasniqi et al., 2017). Such dietary influences can further accentuate the differences in colouration between male and female red mullets, making it essential to consider both biological and environmental factors when studying their colour characteristics.

The CIELAB colour parameters L*, a*, b*, hue, and chroma can be used to objectively explain the notable colour differences between male and female red mullets. Particularly during breeding seasons, females usually exhibit brighter, more intense colours than males, and these differences are impacted by both hereditary and environmental influences.

CONCLUSION

In summary, although specific studies focusing only on L*, a*, and b* values of blunt-snouted mullet in the Black Sea are limited, the existing literature in the Mediterranean provides a basis for understanding how environmental factors and physiological conditions affect the colouration of this species. Future research could benefit from a targeted investigation of these colour metrics in both regions to improve our understanding of the ecological and health implications for red mullet.

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COMPLIANCE WITH ETHICAL STANDARDS

Authors' Contributions

HAD: Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing

SÖ: Investigation, Methodology, Data curation, Formal analysis, Writing – review & editing

All authors read and approved the final version of the article.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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Data Availability

The data supporting the findings of this study are available from the corresponding author upon request.

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