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RESEARCH ARTICLE

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Impact of different cooking methods on the proximate chemical and fatty acid composition of blackspot seabream (*Pagellus bogaraveo*) and blackbelly rosefish (*Helicolenus dactylopterus*) from the North Atlantic Azores (Portugal) Archipelago

Impacto de diferentes métodos culinários na composição proximal química e em ácidos graxos do goraz (*Pagellus bogaraveo*) e do boca negra (*Helicolenus dactylopterus*) provenientes do Arquipélago dos Açores (Portugal) no Atlântico Norte

Joana Filipa Furtado Goulart [a,*], Alexandre Correia Pereira [a], Ana Sofia Ribeiro de Oliveira [a], António Manuel Barros Marques [b], Inês do Carmo Alves Martins [a]

[a] Institute of Marine Sciences - Okeanos, University of the Azores, 9901-862, Horta, Portugal
[b] IPMA - Portuguese Institute for Sea and Atmosphere, 1449-006, Lisbon, Portugal

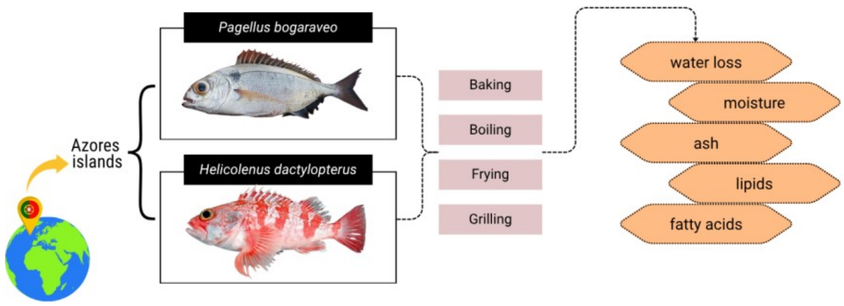
Abstract
Demersal fish are essential to the gastronomy and economy of the Azores (Portugal), highlighting the importance of preserving their nutritional quality, which requires further research regarding the suitability of the cooking methods applied. The aim of this study was to evaluate the proximate composition and fatty acid profile of blackspot seabream (*Pagellus bogaraveo*) and blackbelly rosefish (*Helicolenus dactylopterus*) following different cooking methods (baking, boiling, frying and grilling) in order to conclude which is most suitable for preserving the nutritional quality of each species. Parameters such as water loss (calculation), moisture and ash (thermogravimetry), total fat (acid hydrolysis with extraction process) and fatty acid profile (gas chromatography with flame ionization detection) were analyzed. One-way analysis of variance (ANOVA) was conducted to compare sample means and identify significant differences between species. The obtained results indicated that grilling retained the highest mineral content, while all cooking methods resulted in unsaturated fatty acids/saturated fatty acids ratios above recommended values, confirming the high nutritional quality of both species. Based on polyunsaturated fatty acids composition and lipid health indices (fresh-lipid quality, atherogenicity index, thrombogenicity index, health-promoting index, polyene index, and hypocholesterolemic/hypercholesterolemic ratio), grilling was the most suitable method for blackspot seabream (*Pagellus bogaraveo*), whereas boiling was optimal for blackbelly rosefish (*Helicolenus dactylopterus*). These findings highlight the impact of cooking methods on these fish species nutritional value, reinforcing their role in promoting cardiovascular health.

Keywords: Demersal fish. Cooking methods. Nutritional quality. Fatty acid composition. Fish quality. Azores archipelago. Consumers health.

Resumo
O pescado demersal é essencial para a gastronomia e economia dos Açores (Portugal), destacando-se a importância da preservação da sua qualidade nutricional, o que requer mais investigação relativamente à adequabilidade dos métodos culinários aplicados. O objetivo deste estudo foi avaliar a composição proximal e o perfil de ácidos graxos do goraz (*Pagellus bogaraveo*) e do boca negra (*Helicolenus dactylopterus*) após diferentes métodos culinários (assar, cozer, fritar e grelhar), de modo a concluir qual o mais adequado para preservar a qualidade nutricional de cada espécie. Foram analisados parâmetros como perda de água (cálculo), umidade e cinzas (termogravimetria), gordura total (hidrólise ácida com processo de extração) e perfil de ácidos graxos (cromatografia gasosa com deteção por ionização de chama). Foi efetuada uma análise de variância de uma via (ANOVA) para comparar as médias das amostras e identificar diferenças significativas entre as espécies. Os resultados obtidos indicaram que grelhar reteve o maior teor de minerais, enquanto todos os métodos culinários resultaram em razões de ácidos graxos insaturados/ácidos graxos saturados acima dos valores recomendados, confirmando a elevada qualidade nutricional de ambas as espécies. Com base na composição de ácidos graxos poli-insaturados e nos índices de saúde lipídica (qualidade dos lipídios frescos, índice de aterogenicidade, índice de trombogenicidade, índice de promoção da saúde, índice de polienos e razão hipocolesterolêmico/hipercolesterolêmico), grelhar é o método mais adequado para o goraz (*Pagellus bogaraveo*) enquanto cozer é preferencial para o boca negra (*Helicolenus dactylopterus*). Os resultados realçam o impacto dos métodos culinários no valor nutricional destas espécies de pescado, reforçando o seu papel na promoção da saúde cardiovascular.

Palavras-chave: Pescado demersal. Métodos culinários. Qualidade nutricional. Composição em ácidos graxos. Qualidade do pescado. Arquipélago dos Açores. Saúde dos consumidores.

Graphical Abstract



*Corresponding author: Joana F. F. Goulart. Email Address: joana.ff.goulart@uac.pt
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ROYALDATASET

1. Introduction

The blackspot seabream (*Pagellus bogaraveo*) and the blackbelly rosefish (*Helicolenus dactylopterus*) are among the most economically and gastronomically important demersal teleost species in the Autonomous Region of the Azores (RAA). To enhance the commercial value of these species, it is essential to characterize and promote their nutritional profile, especially in response to the growing demand from consumers and the seafood industry (Duarte et al., 2022; Santos et al., 2019).

On a global scale, fish has gained significant recognition due to its unique nutritional composition and associated health benefits (Ahmed et al., 2022). Portugal exhibits one of the highest per capita seafood consumption rates worldwide, more than twice the European average. Within Portugal, the Azores registers the highest per capita intake of fishery products, with 20.5 kg/capita in 2018 (Maulvault et al., 2012; Valério et al., 2023). The fishing sector in the Azores plays a fundamental socio-economic and development role, contributing to both regional and national economies (Fernández-Palacios et al., 2023; Pereira et al., 2022). Additionally, it represents the primary human-driven influence on the marine ecosystem of the Azores, emphasizing the need to assess and optimize the value of commercially exploited fish species (Costa et al., 2024; Torres et al., 2022). Although past and ongoing research efforts have been increasing the knowledge about the ichthyofauna of the RAA, significant knowledge gaps remain, requiring further investigation to support sustainable fisheries management (Fernández-Palacios et al., 2023; Santos et al., 2019).

The Mediterranean diet is characterized by the regular consumption of fish and has been widely recognized as one of the healthiest and most nutritionally balanced dietary patterns. Several studies have demonstrated its ability to provide vitamins, minerals and polyunsaturated fatty acids of high nutritional value, contributing to improved health, increasing life expectancy and reduced mortality rates (Marques et al., 2019; Tilami & Sampels, 2018). In fact, fish consumption is associated with numerous health benefits due to its antioxidant, anti-inflammatory, wound-healing, neuroprotective, cardioprotective and hepatoprotective properties. In this context, organizations such as the World Health Organization (WHO) recommend the regular intake of fish at least twice per week (WHO, 2002).

The proximate composition of fish species is influenced not only by intrinsic and extrinsic factors such as, genetic characteristics, habitat, diet composition, feeding habits, feeding rate, sex, age, tissue and size, but also by the cooking methods applied (Begum et al., 2016). Cooking fish before consumption is important for ensuring food safety and preserving nutritional quality, as different cooking methods and temperatures significantly influence nutrient retention and the reduction of biological risks. In addition, cooking induces chemical, physical and organoleptic changes, which vary depending on the cooking technique used and the fish species being processed (Maulvault et al., 2012). Culinary processing enhances the edibility and digestibility of fish. However, certain methods may lead to undesirable effects, such as nutritional loss due to lipid oxidation or structural modification of proteins (Maulvault et al., 2012; Uran & Gokoglu, 2014). The primary mechanisms responsible for changes in the nutritional composition of fish during cooking include the absorption of cooking fats, moisture loss, leaching of fat-soluble molecules and oxidation reactions caused by free radicals generated during fat heating (Sioen et al., 2006; Weber et al., 2008). Providing nutritional information on cooked fish is essential to guide consumers toward healthier cooking practices. Understanding the nutritional composition of different species and its relationship with the applied culinary methods allows consumers to make informed dietary choices based on their specific needs (Ahmed et al., 2022).

The assessment of fish muscle moisture content is crucial for estimating its nutrient composition, as its percentage serves as a key indicator of nutritional quality and food preservation safety (Barua et al., 2022). The distribution and mobility of water within the muscle significantly influence fish muscle quality, affecting parameters such as juiciness, tenderness and appearance. The rate of water loss is an important indicator that quantifies the proportion of total water in the muscle that can be released under applied force (An et al., 2013). Additionally, assessing the lipid profile is a key indicator of fish quality, as fish are recognized as rich sources of omega-3 polyunsaturated fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). These bioactive compounds contribute to health promotion, contributing to the prevention and management of cardiovascular, immunological, inflammatory, and neurological diseases (Tilami & Sampels, 2018). Furthermore, quantifying the ash content in fish provides insight into its mineral composition, reflecting its total inorganic content (Ahmed et al., 2022). This mineral composition encompasses essential nutrients such as potassium, calcium, phosphorus, iodine and selenium, which play vital roles in energy metabolism, bone health and thyroid function, among other physiological processes (Ryu et al., 2021; Tilami & Sampels, 2018).

Given the urgent need to enhance the value of demersal fish species in the Azores by prioritizing quality over mass capture, and the lack of studies on the impact of culinary processes on their nutritional composition, it is important to highlight their rich nutritional profile and identify the most suitable cooking methods to optimize their quality. Therefore, this study aims to investigate and evaluate the nutritional changes in blackspot seabream (*Pagellus bogaraveo*) and blackbelly rosefish (*Helicolenus dactylopterus*) following preparation using four different cooking methods, which are among the most commonly used to these species.

2. Materials and Methods

2.1. Sample collection and preparation

Fish specimens were collected in the Azorean Exclusive Economic Zone (EEZ), namely at Condor (38° 32' N 29° 2' W) and Princesa Alice (37° 48' N, 29° 15' W) seamounts, during the institutional annual fishing survey campaigns, using bottom longline in different transects. Specimens were preserved on ice until arriving at the laboratory facilities. Additionally, several fish specimens were obtained from the commercial fish market and sampled immediately after acquisition. One hundred specimens per species of blackspot seabream (*Pagellus bogaraveo*) and blackbelly rosefish (*Helicolenus dactylopterus*) were sampled. Pre-gutted fish were carefully fileted, the skin removed, washed and cooked. Samples were divided in 5 groups of 20 individuals each: raw (referred to as “control”, immediately stored at −80ºC to further analysis), baked, boiled, fried and grilled. The samples were weighed and subjected to culinary treatments without the addition of salt, following the traditional household procedures.

1. **Baking**: Fish fillets were baked in an electrically operated oven (2900 W, Hotpoint Ariston, Italy) at 180 ºC with the fan on for 20 min.
2. **Boiling**: Fish fillets were boiled in water for 15 min.
3. **Frying**: Fish fillets were fried in a pan containing 300 mL of preheated food vegetable oil (Fula), containing sunflower and maize oils, at 180 ºC for 16 min (8 min per side). The oil was purchased in sealed commercial plastic bottles.
4. **Grilling**: Fish fillets were cooked using an electrically operated grill (1600 W, Becken, Portugal) at 180 ºC for 20 min (10 min per side).

After the culinary treatments, fish samples were drained on absorbent paper towels to remove excess cooking oil or water, cooled at room temperature for 30 min, and reweighed to calculate water loss. The samples were then stored at −80ºC for further analysis of moisture, ash, total fat content and fatty acids composition, including saturated, monounsaturated and polyunsaturated fatty acids. No experiments have been performed on live animals.

2.2. Water loss calculi

The percentage of water loss (WL) in fish samples for each cooking method was determined using the following calculation:

WL= [(Initial weight – weight after cooking)/ initial weight] × 100

2.3. Chemical analysis

Fish nutritional composition was determined by an independent and certified external laboratory (SGS Portugal S.A.). Samples were pooled and four replicates from each pool were analysed. Moisture was obtained by thermogravimetry by measuring the mass of the samples over time using a thermogravimetric analyser (LECO, 604-100-700, TGA 701/ 105 ± 2 ºC) according to NP 872 and NP 1614-1 (Norma Portuguesa, 2000, 2009) as well as ash content (LECO, 604-100-700, TGA 701/ 550 ± 20 ºC) according to NP 1615 (Norma Portuguesa, 2002). Total fat was determined by acid hydrolysis with solvent extraction on a Soxtec fat extractor (FOSS, Soxtec 8000) according to NP ISO 6492:2014 and ISO 6498:2012 (International Organization for Standardization, 2012; Norma Portuguesa, 2014). Gas chromatography (GC) with a flame ionization detector (FID) was applied to quantified saturated, monounsaturated and polyunsaturated fatty acids as well as the fatty acids profile according to ISO 12966 (Agilent Technologies, 7820 A).

All methods were carried out in accordance with relevant guidelines and regulations.as well as all experimental protocols were approved by a named institutional and/or licensing committee/s.

2.4. Nutritional Indices

From the data on fatty acid composition, lipid quality indices were calculated as presented in the **Table 1**.

Table 1 Calculation formulas used to determine lipid quality indices.

Index	Formula	Ref
Sum of SFAs (SFA)	Σ (C6:0, C8:0, C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, C20:0)	-
Sum of MUFAs (MUFA)	Σ (C14:1n5, C16:1n7, C17:1n7, C18:1n9t, C18:1n9c, C20:1n9, C22:1n9)	-
Sum of PUFAs (PUFA)	Σ (C18:2n6t, C18:2n6c, C18:3n6, C18:3n3, C20:2n6, C20:3n3, C20:3n6, C20:4n6, C20:5n3, C22:6n3)	-
Hypocholesterolemic/hypercholesterolemic ratio (h/H)	[(C18:1 + C18:2 + C18:3 + C20:3 + C20:4 + C20:5 + C22:4 + C22:5 + C22:6) / (C14:0 + C16:0)]	Duyar & Bayrakli (2023)
Atherogenicity Index (AI)	[C12:0 + (4 × C14:0) + C16:0] / ((n-3) PUFA + (n-6)PUFA + MUFA)	Duyar & Bayrakli (2023) Ulbricht & Southgate (1991)
Thrombogenicity Index (TI)	[C14:0 + C16:0 + C18:0] / [(0.5 × MUFA) + (0.5 × (n-6)PUFA) + (3 × (n-3)PUFA) + (n-3)PUFA/(n 6) PUFA]	Duyar & Bayrakli (2023) Ulbricht & Southgate (1991)
Flesh-lipid quality (FLQ)	100 * (EPA + DHA) / total fatty acids	Abrami et al. (1992)
Health-promoting index (HPI)	UNSAT / [C12:0 +(C14:0 × 4) + C16:0]	Chen et al. (2004)
Polyene index (PI)	(C20:5 + C22:6) / C16:0	Lubis & Buckle (2007)

2.5. Statistical analysis

Using the Microsoft Excel software, one-way analysis of variance (ANOVA) was conducted to compare sample means and identify significant differences between species regarding nutritional composition, fatty acids content and nutritional value index (**Tables S1-S5**). The assumptions of data normality and homogeneity of variance, required for ANOVA, were validated using the Kolmogorov-Smirnov test and Levene's test, respectively. For post hoc multi-comparisons (*F*-value and *p*-value), Tukey's test was applied with a significance level of 0.05.

3. Results

3.1. Water loss, moisture, ash and total fat contents

Significant differences (Tukey test, $p<0.05$) were observed in water loss, moisture and ash content among *P. bogaraveo* samples subjected to different cooking methods, as well as among *H. dactylopterus* samples under the same conditions (**Table 2**).

Table 2 Effect of different cooking methods on water loss, moisture content, ash content and total fat content of *P. bogaraveo* and *H. dactylopterus*. Values are presented as mean ± standard deviation. In each row, different superscript letters indicate statistically significant differences between cooking methods for each species (Tukey test, $p<0.05$).

Component (% of wet weight)	*P. bogaraveo*				
	Raw	Baked	Boiled	Fried	Grilled
Water loss	-	31.8^{b} ± 9.8	24.1^{c} ± 4.3	37.5^{a} ± 5.1	30.8^{b} ± 5.8
Moisture	77.7^{a} ± 1.6	68.5^{bc} ± 4.2	69.9^{b} ± 3.2	59.0^{d} ± 4.7	66.7^{c} ± 3.2
Ash	2.1^{b} ± 0.1	2.2^{a} ± 0.5	1.3^{c} ± 0.2	1.5^{c} ± 0.6	2.2^{ab} ± 0.3
Total Fat	2.1^{b} ± 0.4	4.1^{b} ± 1.9	7.0^{a} ± 0.7	5.6^{ab} ± 0.7	3.0^{b} ± 1.2
	H. dactylopterus				
Water loss	-	43.2^{a} ± 7.8	30.5^{c} ± 4.5	45.0^{a} ± 5.1	35.4^{b} ± 5.6
Moisture	78.1^{a} ± 1.3	63.2^{c} ± 5.6	74.5^{b} ± 1.6	56.4^{d} ± 3.7	67.1^{c} ± 3.9
Ash	1.7^{a} ± 0.1	1.2^{c} ± 0.2	0.9^{d} ± 0.1	1.7^{a} ± 0.2	1.4^{b} ± 0.1
Total Fat	4.3 ± 0.9	4.3 ± 1.1	5.0 ± 1.3	5.0 ± 1.5	3.4 ± 1.2

For *P. bogaraveo*, the lowest water loss was recorded in boiled samples (24.1% w/w), while fried samples exhibited the highest (37.5% w/w). In opposition, moisture content was highest in boiled samples (69.9% w/w) and lowest in fried samples (59.0% w/w). Ash content was significantly higher in baked and grilled samples (2.2% w/w) compared to boiled and fried samples, which showed the lowest values (1.3% w/w). In terms of total fat content, the highest percentage was found in boiled samples (7.0% w/w) whereas grilled samples had the lowest (3.0% w/w).

A similar trend was observed for *H. dactylopterus*. Water loss was lowest in boiled samples (30.5% w/w) and highest in baked and fried samples (43.2% w/w; 45.0% w/w). Moisture content was highest in boiled samples (74.5% w/w) and lowest in fried samples (56.4% w/w). Regarding ash content, fried samples exhibited the highest value (1.7% w/w), while boiled samples had the lowest (0.9% w/w). Total fat content was highest in boiled and fried samples (5.0% w/w), whereas grilled samples had the lowest value (3.4% w/w), with no statistically significant differences.

3.2. Fatty acid profile

The fatty acid profile of fish muscle subjected to different cooking methods was analysed to assess their impact on the nutritional value of the two studied species (**Table 3** and **Table 4**). Significant differences in fatty acid composition were observed in both species (Tukey test, p<0.05).

Table 3 Effect of different cooking methods on content (% wet weight) of the main fatty acid groups components (SFA(s), MUFA(s) and PUFA(s)) and nutritional value parameters (AI, TI, h/H, FLQ, HPI and PI) of *P. bogaraveo*.

Component	*P. bogaraveo*				
	Raw	**Baked**	**Boiled**	**Fried**	**Grilled**
Caproic acid (C6:0)	<LOD	<LOD	<LOD	<LOD	<LOD
Caprylic acid (C8:0)	<LOD	<LOD	<LOD	<LOD	<LOD
Lauric acid (C12:0)	<LOD	<LOD	<LOD	<LOD	<LOD
Myristic acid (C14:0)	$0.2^{b} \pm 0.0$	$0.4^{ab} \pm 0.1$	$0.6^{a} \pm 0.3$	$0.2^{b} \pm 0.1$	$0.2^{b} \pm 0.1$
Pentadecanoic acid (C15:0)	<LOD	0.1 ± 0.1	0.1 ± 0.0	<LOD	0.1 ± 0.0
Palmitic acid (C16:0)	$0.5^{b} \pm 0.1$	$1.5^{ab} \pm 0.6$	$2.1^{a} \pm 0.7$	$1.0^{ab} \pm 0.7$	$0.7^{b} \pm 0.4$
Heptadecanoic acid (C17:0)	<LOD	0.1 ± 0.1	0.1 ± 0.1	<LOD	<LOD
Stearic acid (C18:0)	$0.2^{b} \pm 0.0$	$0.5^{ab} \pm 0.2$	$0.6^{a} \pm 0.2$	$0.4^{ab} \pm 0.2$	$0.2^{b} \pm 0.1$
Arachidic acid (C20:0)	<LOD	0.1 ± 0.1	0.1 ± 0.1	<LOD	<LOD
Total SFA	**$1.0^{b} \pm 0.2$**	**$2.9^{ab} \pm 1.3$**	**$3.6^{a} \pm 1.3$**	**$2.1^{ab} \pm 1.0$**	**$1.3^{b} \pm 0.7$**
cis-9-Tetradecenoic acid (C14:1n5)	<LOD	<LOD	<LOD	<LOD	<LOD
Palmitoleic acid (C16:1n7)	0.1 ± 0.0	0.1 ± 0.1	0.2 ± 0.1	0.1 ± 0.0	0.2 ± 0.1
cis-10-Heptadecenoic acid (C17:1n7)	<LOD	0.1 ± 0.0	0.1 ± 0.0	<LOD	<LOD
Elaidic acid + Oleic acid (C18:1n9*t* + C18:1n9*c*)	0.5 ± 0.1	0.8 ± 0.6	1.0 ± 0.8	1.1 ± 0.3	0.7 ± 0.4
Erucic acid (C22:1n9)	<LOD	<LOD	<LOD	<LOD	0.1 ± 0.0
Total MUFA	**0.6 ± 0.1**	**1.2 ± 0.9**	**1.4 ± 0.8**	**1.2 ± 0.5**	**1.2 ± 0.6**
Linoleic acid + Linolelaidic acid (C18:2n6*c* + C18:2n6*t*)	<LOD	$0.1^{b} \pm 0.0$	$0.4^{ab} \pm 0.3$	$0.8^{a} \pm 0.4$	$0.1^{b} \pm 0.0$
γ-L-Linolenic acid [GLA] (C18:3n6)	<LOD	<LOD	<LOD	<LOD	<LOD
α-Linolenic acid [ALA] (C18:3n3)	<LOD	<LOD	0.1 ± 0.0	0.1 ± 0.1	<LOD
cis-11.14-Eicosadienoic acid (C20:2n6)	<LOD	<LOD	0.1 ± 0.1	0.1 ± 0.0	0.1 ± 0.0
cis-8.11.14-Eicosatrienoic acid [DGLA] (C20:3n6)	<LOD	<LOD	<LOD	<LOD	<LOD
Arachidonic acid [AA] (C20:4n6)	<LOD	<LOD	<LOD	<LOD	<LOD
cis-11.14.17-Eicosatrienoic acid [ETE] (C20:3n3)	<LOD	<LOD	<LOD	<LOD	<LOD
cis-5.8.11.14.17- Eicosapentaenoic acid [EPA] (C20:5n3)	<LOD	0.1 ± 0.0	0.1 ± 0.0	<LOD	0.1 ± 0.0
cis-4.7.10.13.16.19- Docosahexaenoic acid [DHA] (C22:6n3)	0.2 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.2 ± 0.1
Total PUFA	**$0.3^{b} \pm 0.1$**	**$0.4^{b} \pm 0.1$**	**$1.4^{a} \pm 0.2$**	**$1.5^{a} \pm 0.7$**	**$0.5^{b} \pm 0.4$**
Nutritional Quality Parameters					
Total n-3 PUFA	$0.3^{a} \pm 0.1$	$0.1^{b} \pm 0.0$	$0.2^{ab} \pm 0,0$	$0.3^{a} \pm 0.1$	$0.3^{a} \pm 0.1$
EPA + DHA	$0.2^{ab} \pm 0.0$	$0.1^{b} \pm 0,0$	$0.1^{b} \pm 0.0$	$0.1^{b} \pm 0.1$	$0.3^{a} \pm 0.1$
Total n-6 PUFA	<LOD	$0.1^{b} \pm 0.0$	$0.6^{ab} \pm 0.3$	$1.0^{a} \pm 0.4$	$0.1^{b} \pm 0.0$
PUFA/SFA	0.3 ± 0.1	0.1 ± 0.1	0.2 ± 0.2	0.5 ± 0.4	0.3 ± 0.3
MUFA/SFA	0.8 ± 0.2	0.3 ± 0.3	0.3 ± 0.2	0.6 ± 0.4	0.9 ± 0.6
UFA/SFA	1.1 ± 0.3	0.3 ± 0.2	0.5 ± 0.4	1.1 ± 0.8	1,2 ± 0.7
n-6/n-3	<LOD	$0.8^{b} \pm 0.0$	$3.7^{a} \pm 0.0$	$4.0^{a} \pm 1,1$	$0.3^{b} \pm 0.2$
n-3/n-6	<LOD	$1.3^{b} \pm 0.0$	$0.3^{b} \pm 0.0$	$0.3^{b} \pm 0.2$	$4.0^{a} \pm 2.1$
AI	<LOD	$2.2^{a} \pm 0.5$	$2.0^{a} \pm 0.5$	$0.7^{b} \pm 0.2$	$0.9^{b} \pm 0.2$
TI	<LOD	$1.1^{ab} \pm 0.4$	$1.7^{a} \pm 0.5$	$0.7^{bc} \pm 0.3$	$0.2^{c} \pm 0.1$
h/ H	$1.0^{bc} \pm 0.2$	$0.6^{c} \pm 0.1$	$0.6^{c} \pm 0.1$	$1.8^{a} \pm 0.3$	$1.2^{b} \pm 0.2$
FLQ	$9.5^{a} \pm 0.0$	$2.2^{b} \pm 0.0$	$1.6^{b} \pm 0.0$	$2.1^{b} \pm 0.0$	$10.1^{a} \pm 0,2$
HPI	$0.8^{b} \pm 0.1$	$0.5^{b} \pm 0.1$	$0.6^{b} \pm 0.2$	$1.5^{a} \pm 0.5$	$1.1^{ab} \pm 0.3$

Values are presented as mean ± standard deviation. In each row, different superscript letters indicate statistically significant differences between cooking methods for each species (Tukey test, p<0.05). LOD - Limit of detection (0.1% of wet weight).

In *P. bogaraveo* (**Table 3**), the saturated fatty acid (SFA) fraction ranged from 1.3% (w/w) in grilled *samples* to 3.6% (w/w) in boiled samples. Myristic acid (C14:0) was significantly higher in boiled samples (1.3% w/w) and lower in fried and grilled samples (0.2% w/w). Pentadecanoic acid (C15:0) was not detected in fried samples and remained stable at 0.2% w/w across other cooking methods. Palmitic acid (C16:0) and stearic acid (C18:0) were most abundant in boiled samples (2.1% w/w and 0.6% w/w, respectively) and least abundant in grilled ones (0.7% w/w and 0.2% w/w, respectively). Heptadecanoic acid (C17:0) and arachidic acid (C20:0) were exclusively found in baked and boiled samples (0.1% w/w).

In *H. dactylopterus* (**Table 4**), the SFA fraction varied between 1.5% (w/w) in fried samples and 2.1% (w/w) in boiled samples, with no significant differences detected. Myristic acid (C14:0) was significantly higher in baked and boiled samples (0.3% w/w) and lower in fried ones (0.1% w/w). Pentadecanoic acid (C15:0) was only detected in baked and boiled samples at 0.1% w/w. Palmitic acid (C16:0) was highest in boiled samples (1.2% w/w) and lowest in fried and grilled ones (0.8% w/w), with no significant differences. Stearic acid (C18:0) also showed no significant differences, with lower values in grilled samples (0.2% w/w) and 0.3% (w/w) in all other cooking methods. Arachidic acid (C20:0) was only detected in baked samples (0.1% w/w).

The monounsaturated fatty acid (MUFA) fraction in *P. bogaraveo* did not show significant differences between cooking treatments, with a maximum of 1.4% (w/w) in boiled samples and 1.2% (w/w) in the others. Palmitoleic acid (C16:1n7) was more abundant in boiled and grilled samples (0.2% w/w). Cis-10-Heptadecenoic acid (C17:1n7) was only detected in baked and boiled samples. The sum of elaidic and oleic acids (C18:1n9t c) varied from 0.7% (w/w) in grilled samples and 1.1% (w/w) in fried ones. None of the MUFA components showed any statistically significant difference among the cooking treatments applied.

Similarly, in *H. dactylopterus*, the MUFA fraction ranged from 1.4% in grilled samples to 2.0% w/w in boiled and fried ones, with no significant differences registered among cooking treatments, as observed in P. *bogaraveo.* Palmitoleic acid (C16:1n7) was significantly higher in boiled samples (0.4% w/w) and lower in fried ones (0.1% w/w). The sum of elaidic and oleic acids (C18:1n9t c) ranged from 0.9% (w/w) in grilled samples and 1.7% (w/w) in fried ones. Erucic acid (C22:1n9) was only detected in boiled samples (0.1% w/w).

The polyunsaturated fatty acid (PUFA) fraction in *P. bogaraveo* varied significantly between 0.4% (w/w) in baked samples and 1.5% (w/w) in fried ones. The sum of linoleic acid and linolelaidic acid (C18:2n6*c* + C18:2n6*t*) presented the same minimum value of 0.1% (w/w) in baked and grilled samples, reaching a maximum of 0.8% (w/w) in fried samples. At the minimum detection threshold of the applied analytical method (0.1% w/w), alfa-linolenic acid (C18:3n3) was detected in boiled and fried samples, *cis*-11.14-Eicosadienoic acid (C20:2n6) in boiled, fried and grilled samples, and EPA (C20:5n3) in baked, boiled and grilled samples. DHA (C22:6n3) reached 0.2% (w/w) in grilled samples, while other cooking methods resulted in a percentage of 0.1% (w/w).

Table 4 Effect of different cooking methods on content (% wet weight) of the main fatty acid groups components (SFA(s), MUFA(s) and PUFA(s)) and nutritional value parameters (AI, TI, h/H, FLQ, HPI and PI) of *H. dactylopterus*.

Component	***H. dactylopterus***				
	Raw	**Baked**	**Boiled**	**Fried**	**Grilled**
Caproic acid (C6:0)	<LOD	<LOD	<LOD	<LOD	<LOD
Caprylic acid (C8:0)	<LOD	<LOD	<LOD	<LOD	<LOD
Lauric acid (C12:0)	<LOD	<LOD	<LOD	<LOD	<LOD
Myristic acid (C14:0)	$0.2^{ab} \pm 0.0$	$0.3^{a} \pm 0.1$	$0.3^{a} \pm 0.1$	$0.1^{b} \pm 0.0$	$0.2^{ab} \pm 0.1$
Pentadecanoic acid (C15:0)	<LOD	0.1 ± 0.0	0.1 ± 0.0	<LOD	<LOD
Palmitic acid (C16:0)	0.9 ± 0.1	1.1 ± 0.4	1.2 ± 0.2	0.8 ± 0.2	0.8 ± 0.1
Heptadecanoic acid (C17:0)	<LOD	<LOD	<LOD	<LOD	<LOD
Stearic acid (C18:0)	0.2 ± 0.0	0.3 ± 0.1	0.3 ± 0.0	0.3 ± 0.1	0.2 ± 0.0
Arachidic acid (C20:0)	<LOD	0.1 ± 0.1	<LOD	<LOD	<LOD
Total SFA	**1.3 ± 0.3**	**2.0 ± 0.6**	**2.1 ± 0.4**	**1.5 ± 0.4**	**1.6 ± 0.3**
cis-9-Tetradecenoic acid (C14:1n5)	<LOD	<LOD	<LOD	<LOD	<LOD
Palmitoleic acid (C16:1n7)	$0.3^{ab} \pm 0.1$	$0.3^{ab} \pm 0.1$	$0.4^{a} \pm 0.0$	$0.1^{c} \pm 0.1$	$0.2^{bc} \pm 0.1$
cis-10-Heptadecenoic acid (C17:1n7)	<LOD	<LOD	<LOD	<LOD	<LOD
Elaidic acid + Oleic acid (C18:1n9*t* + C18:1n9*c*)	1.2 ± 0.2	1.2 ± 0.4	1.3 ± 0.3	1.7 ± 0.5	0.9 ± 0.3
Erucic acid (C22:1n9)	<LOD	<LOD	0.1 ± 0.1	<LOD	<LOD
Total MUFA	**1.5 ± 0.3**	**1.8 ± 0.5**	**2.0 ± 0.5**	**2.0 ± 0.5**	**1.4 ± 0.7**
Linoleic acid + Linolelaidic acid (C18:2n6*c* + C18:2n6*t*)	<LOD	$0.1^{b} \pm 0.0$	$0.1^{b} \pm 0.0$	$1.2^{a} \pm 0.7$	$0.1^{b} \pm 0.0$
γ-L-Linolenic acid [GLA] (C18:3n6)	<LOD	<LOD	<LOD	<LOD	<LOD
α-Linolenic acid [ALA] (C18:3n3)	<LOD	<LOD	<LOD	<LOD	<LOD
cis-11.14-Eicosadienoic acid (C20:2n6)	<LOD	<LOD	<LOD	<LOD	<LOD
cis-8.11.14-Eicosatrienoic acid [DGLA] (C20:3n6)	<LOD	<LOD	<LOD	<LOD	<LOD
Arachidonic acid [AA] (C20:4n6)	<LOD	<LOD	<LOD	<LOD	<LOD
cis-11.14.17-Eicosatrienoic acid [ETE] (C20:3n3)	<LOD	<LOD	<LOD	<LOD	<LOD
cis-5.8.11.14.17- Eicosapentaenoic acid [EPA] (C20:5n3)	0.1 ± 0.0	0.1 ± 0.0	0.2 ± 0.1	<LOD	0.1 ± 0.1
cis-4.7.10.13.16.19- Docosahexaenoic acid [DHA] (C22:6n3)	$0.7^{a} \pm 0.1$	$0.2^{c} \pm 0.1$	$0.6^{ab} \pm 0.3$	$0.1^{c} \pm 0.1$	$0.3^{bc} \pm 0.1$
Total PUFA	**1.0 ± 0.2**	**0.4 ± 0.2**	**1.0 ± 0.4**	**1.4 ± 1.1**	**0.5 ± 0.2**
Nutritional Quality Parameters					
Total n-3 PUFA	$0.9^{a} \pm 0.1$	$0.3^{b} \pm 0.1$	$0.8^{a} \pm 0.3$	$0.1^{b} \pm 0.1$	$0.3^{b} \pm 0.1$
EPA + DHA	$0.8^{a} \pm 0.1$	$0.3^{b} \pm 0.1$	$0.8^{b} \pm 0.3$	$0.1^{b} \pm 0.1$	$0.3^{b} \pm 0.1$
Total n-6 PUFA	<LOD	$0.1^{b} \pm 0.0$	$0.1^{b} \pm 0.0$	$1.2^{a} \pm 0.7$	$0.1^{b} \pm 0.0$
PUFA/SFA	$0.6^{ab} \pm 0.16$	$0.2^{b} \pm 0.1$	$0.5^{ab} \pm 0.0$	$1.0^{a} \pm 0.5$	$0.4^{b} \pm 0.1$
MUFA/SFA	1.0 ± 0.25	0.9 ± 0.4	1.0 ± 0.3	1.4 ± 0.5	0.9 ± 0.4
UFA/SFA	$1.6^{b} \pm 0.31$	$1.1^{bc} \pm 0.3$	$1.4^{b} \pm 0.2$	$2.4^{a} \pm 0.6$	$0.6^{c} \pm 0.2$
n-6/n-3	<LOD	$0.1^{b} \pm 0.1$	$0.1^{b} \pm 0.0$	$8.2^{a} \pm 0.0$	$0.2^{b} \pm 0.1$
n-3/n-6	<LOD	$8.7^{b} \pm 0.9$	$20.0^{a} \pm 3.1$	$0.1^{c} \pm 0.0$	$6.4^{b} \pm 0.9$
AI	<LOD	$1.1^{a} \pm 0.1$	$0.9^{a} \pm 0.1$	$0.4^{b} \pm 0.0$	$1.0^{a} \pm 0.2$
TI	<LOD	$0.2^{b} \pm 0.0$	$0.1^{b} \pm 0.0$	$0.6^{a} \pm 0.1$	$0.2^{b} \pm 0.0$
h/ H	$1.8^{b} \pm 0.3$	$1.1^{c} \pm 0.2$	$1.5^{bc} \pm 0.2$	$3.3^{a} \pm 0.5$	$1.4^{bc} \pm 0.3$
FLQ	$18.2^{a} \pm 0.0$	$7.1^{b} \pm 0.0$	$16.0^{a} \pm 0.1$	$2.1^{c} \pm 0.0$	$8.6^{b} \pm 0.1$
HPI	$1.6^{b} \pm 0.23$	$1.0^{c} \pm 0.1$	$0.1^{d} \pm 0.0$	$2.9^{a} \pm 0.2$	$1.2^{c} \pm 0.0$

Values are presented as mean ± standard deviation. In each row, different superscript letters indicate statistically significant differences between cooking methods for each species (Tukey test, p<0.05). LOD - Limit of detection (0.1% of wet weight).

The PUFA fraction in *H. dactylopterus* ranged from 0.4% (w/w) in baked samples to 1.4% (w/w) in fried samples, with no significant differences (Tukey test, p>0.05). The sum of linoleic acid and linolelaidic acid (C18:2n6c + C18:2n6t) presented a maximum value of 1.2% (w/w) in fried samples, with a significant difference (Tukey test, p<0.05), and a minimum of 0.1% (w/w) in samples subjected to all other cooking procedures. EPA (C20:5n3) was detected at 0.1% (w/w) in baked and grilled samples and at 0.2% (w/w) in boiled samples. DHA (C22:6n3) showed a significant variation, ranging from 0.1% (w/w) in fried samples to 0.6% (w/w) in boiled samples.

Based on quality indices, significant variations (Tukey test, p<0.05) among culinary treatments were also observed in both species under study (**Table 3** and **Table 4**). Regarding *P. bogaraveo*, EPA + DHA had the highest value of 0.3% (w/w) in grilled samples, maintaining the value of 0.1% w/w for the other cooking methods. The n-6/n-3 ratio was lower in grilled samples (0.3) and higher in the fried ones (4.0), while the n-3/n-6 ratio followed the opposite trend, with the highest value in grilled samples (4.0) and a lowest in fried ones (0.3). AI varied from 0.7 in fried samples to 2.2 in baked ones; TI from 0.2 in grilled to 1.7 in boiled; h/H from 0.6 in baked and boiled samples to 1.8 in fried; FLQ varied from 1.6 in boiled to 10.1 in grilled samples; HPI from 0.5 in baked to 1.5 in fried, and PI reached a maximum of 0.4 in grilled samples, while all others presented a value of 0.1. In relation to PUFA/SFA, MUFA/SFA and UFA/SFA ratios, no significant differences were found among the applied cooking methods.

In *H. dactylopterus*, the n-6/n-3 ratio was lowest in baked and boiled samples (0.1) and highest in fried ones (8.2), while the n-3/n-6 ratio was highest in boiled samples (20.0) and lowest one in fried ones (0.1). AI varied from 0.4 in fried samples to 1.1 in baked ones; TI from 0.1 in boiled to 0.6 in fried samples; h/H from 1.1 in baked to 3.3 in fried samples; FLQ from 2.1 in fried to 16.0 in boiled samples; HPI from 0.1 in boiled to 2.9 in fried samples; and PI ranged from 1.0 in baked and fried samples to 2.0 in boiled samples. The PUFA/SFA index was lowest in baked samples (0.2) and highest in boiled ones (0.5), while the UFA/SFA ratio was lowest in grilled samples (0.6) and highest in fried samples (2.4). The sum of EPA and DHA and the MUFA/SFA index showed no statistically significant differences between cooking methods.

4. Discussion

This study demonstrates significant differences in the nutritional profiles of *P. bogaraveo* and *H. dactylopterus* when subjected to distinct cooking methods. Previous studies have indicated that factors such as high cooking temperatures, heat treatment duration and the presence of water or oil can influence the nutritional composition of fish (Tan et al., 2023; Weber et al., 2008).

Following the application of different cooking methods, water content measurements revealed that all methods resulted in some degree of water loss. In both species, the highest water losses were observed in the fried samples, while the lowest losses occurred in the boiled samples. These findings are consistent with the results reported by Mieiro et al. (2016) for other fish species.

Determining the moisture content of fish muscle, after the application of different cooking methods, provides insight into the remaining water content, which directly influences texture, as fish with lower water content tend to exhibit a firmer texture.

Nogueira et al. (2013) in their study of 14 commercially available species from the Northeast Atlantic, reported an average muscle moisture content of approximately 79% (w/w) in raw fish, a finding consistent with our results of 77.7% (w/w) in *P. bogaraveo* and 78.1% (w/w) in *H. dactylopterus*. In both species, frying resulted in the greatest decrease in moisture content, which aligns with findings from the other studies (Asghari et al., 2013; Weber et al., 2008). On the other hand, boiling was the method that resulted in the least moisture loss, with the moisture content remaining closest to the values observed in the raw matrix. This can be attributed to the influence of cooking water, which either mitigates moisture loss or replenishes water naturally present in the fish (Domiszewski et al., 2011; Larsen et al., 2010). The decrease in moisture content is identified as the primary factor contributing to the significant increase in protein, fat, and ash content in cooked fish (García-Arias et al., 2003).

The ash content in fish muscle reflects the total minerals content available to consumers, offering valuable insight into the nutritional value of the food (Tilami & Sampels, 2018). During cooking, the loss of water results in an apparent increase in the percentage of ash, which is inversely proportional to water content. However, in frying, the absorption of oil can camouflage this effect by incorporating additional elements. On the other hand, it is known that cooking methods involving water can lead to the loss of minerals from the fish, thereby reducing the ash percentage (Asghari et al., 2013; Weber et al., 2008), which is consistent with our findings.

In this study, the ash content of the cooked muscle fish ranged from 1.3% (w/w) to 2.2% (w/w) in *P. bogaraveo* and from 0.9% (w/w) to 1.7% (w/w) in *H. dactylopterus*. The values align with those reported in previous studies of various marine species, which documented ranges from 1.0% to 2.6% (w/w) (Asghari et al., 2013), 1.0% to 2.5% (w/w) (Weber et al., 2008) and 1.4% to 2.4% (w/w) (Uran & Gokoglu, 2014). Based on our results, for *P. bogaraveo*, baking and grilling were identified as the most effective cooking methods for preserving mineral content, while for *H. dactylopterus*, frying was the most suitable method, followed by grilling. Considering the impact of oil absorption on the measured values, grilling may be considered the optimal method for preserving *H. dactylopterus* as a source of minerals for consumers.

Lipids play a crucial role in maintaining human health by providing energy, essential fatty acids and fat-soluble nutrients (Tilami & Sampels, 2018). The lipid content analysis of raw fillets from the studied species revealed that *H. dactylopterus* exhibited a considerably higher fat percentage (4.3% w/w) compared to *P. bogaraveo* (2.1% w/w). However, according to the literature, both species can be considered as "lean" fish, as their fat content remains below 5% (w/w), making their consumption beneficial for a healthy diet (Duarte et al., 2022).

Thermal processing can influence lipid extractability in fish due to dissociation of protein-lipid complexes, facilitating lipid release through mechanical factors, as cooked fish tissues became more easily homogenized (Larsen et al., 2010). In *P. bogaraveo*, lipid content increased across all cooking methods, with boiling leading to a more than threefold rise compared to the raw state. This finding contrasts with previous studies reporting lipid leaching into cooking water (Domiszewski et al., 2011; Larsen et al., 2010). The observed deviation may be attributed to factors such as tissue matrix characteristics (*e.g.*, thickness) and the relatively short cooking duration. In contrast, *H. dactylopterus*, did not exhibit significant variation in total lipid content across cooking methods. Notably, grilling resulted in a 21% (w/w) reduction in total fat, not in accordance with the findings of Asghari et al. (2013) and Weber et al. (2008) but in agreement with those of Saldanha & Bragagnolo (2010) who reported that grilling affects cholesterol levels in higher-fat fish, leading to a significant decrease in total lipid content.

During the frying process, the increase in lipid content in both species primarily results from the absorption of frying oil, coinciding with moisture loss through evaporation (Sioen et al., 2006; Uran & Gokoglu, 2014; Weber et al., 2008). Additionally, previous studies have reported an inverse relationship between initial total lipid content and fat absorption during frying, with lower-fat fish tending to adsorb greater amounts of oil compared to higher-fat fish (Sioen et al., 2006; Weber et al., 2008). This trend is consistent with the present findings, as *P. bogaraveo*, being the leaner fish, showed a higher percentage increase in total fat compared to *H. dactylopterus*.

The fatty acid profile of fish subjected to different cooking methods was analysed, as it reflects the nutritional value of the fish and plays a crucial role in the synthesis of eicosanoids, which possess important antithrombotic properties. These compounds contribute to reducing the risk of cardiovascular diseases and play a protective role against cancer, diabetes and other inflammatory and autoimmune disorders (Saldanha & Bragagnolo, 2010; Tilami & Sampels, 2018).

Our results indicate that in *H. dactylopterus*, the proportions of total saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) did not exhibit significant differences among the studied cooking methods. In contrast, *P. bogaraveo* showed significant variations in both SFA and PUFA levels. Cooking led to a higher degree of saturation, with SFA content exceeding three times the value observed in raw samples. Additionally, boiled and fried samples exhibited a substantial increase in total PUFA content, reaching approximately five times the levels found in the raw fish.

The consumption of these fish species offers notable health benefits, as unsaturated fats are considered healthier, contributing to cholesterol reduction and improved cardiovascular health (Tilami & Sampels, 2018). However, differences were observed between the species regarding the impact of cooking methods. *P. bogaraveo* exhibited the least favourable fatty acid ratio when baked or boiled but showed the most favourable ratio when fried or grilled. Conversely, *H. dactyopterus* had the poorest ratio when grilled and the most favourable when fried. These results suggest that the nutritional advantages of consuming fish vary depending on the cooking method used, although the absorption of frying oil, typically of vegetable origin and rich in n-6 fatty acids, must also be considered.

Regarding oxidation reactions involving free radicals generated in heated culinary fats, different fatty acids respond in distinct ways. SFAs are relatively heat-stable at standard cooking temperatures. However, at temperatures exceeding 150°C, various oxidation products can be detected. On the other hand, UFAs are more sensitive to thermal degradation, with their stability decreasing as the degree of unsaturation increases. Therefore, in the presence of oxygen, PUFAs degrade more rapidly, while MUFAs tend to remain stable (Sioen et al., 2006; Weber et al., 2008). The results obtained for *P. bogaraveo*, align with this expected behaviour, reinforcing the influence of cooking methods on fatty acids composition.

Regarding saturated fatty acids (SFAs), lauric (C12:0) and myristic (C14:0) fatty acids are known to promote hypercholesterolemia (Fernandes et al., 2014). In the present study, myristic acid (C14:0) was detected in both species across all cooking methods, highlighting a relevant aspect of their nutritional profile. Significant differences were observed between cooking methods for both species. In *P. bogaraveo*, the highest increase in myristic acid content was associated with baking and boiling, while levels remained unchanged compared to raw samples in fried and grilled fish. In *H. dactylopterus*, myristic acid concentration increased with baking and boiling but decreased during frying. Based on this parameter, the consumption of these species in their boiled and baked form may be considered more beneficial for health.

Regarding the results obtained for MUFA elements, oleic acid (omega-9) is known for its neuroprotective properties and its role in the prevention and treatment of various neurological diseases (Song et al., 2019). The presence of oleic acid was confirmed in the raw fillets of both studied species, consistent with previous findings by Méndez & González (1997) and Huynh & Kitts (2009), who reported its presence in lean fish. Notably, no significant differences in oleic acid content were observed across the different cooking methods in either *P. bogaraveo* or *H. dactylopterus*, indicating its stability during thermal processing. This stability further supports the nutritional benefits of consuming these species, regardless of the cooking method applied.

Regarding PUFAs composition of the cooked samples, long-term consumption of n-3 PUFAs has been associated with a reduced risk of heart disease and hypertension, as well as prevention of blood clots and various types of cancer. Additionally, n-3 PUFAs contribute to normal neurological development in children and may reduce the risk of neurodegenerative disorders such as Alzheimer's disease (Khan et al., 2023; Nogueira et al., 2013). On the other hand, excessive intake of n-6 PUFAs has been linked to an increased risk of cardiovascular disease and obesity (Berber et al., 2024). In this context, our results indicate that both species exhibited higher n-3 PUFA than n-6 PUFA levels in their raw state, reinforcing their potential contribution to a healthy diet. However, this ratio was significantly influenced by the cooking method applied. In *P. bogaraveo*, boiling and frying led to a substantial increase in n-6 PUFA concentration, with the fried sample reaching an undesirable n-6/n-3 ratio of 4.0. In contrast, grilling produced the most favourable n-3/n-6 ratio (4.0). For *H. dactylopterus*, n-6 PUFA levels increased notably only in the fried sample, leading to an unhealthy n-6/n-3 ratio of 8.2. In contrast, boiling resulted in the most favourable n-3/n-6 ratio (20.0), followed by baking (8.7) and grilling (6.4).

Dietary guidelines recommend a weekly intake of 250 to 500 mg of long-chain omega-3 fatty acids EPA + DHA to support overall health (Berber et al., 2024). Our findings indicate a favourable EPA + DHA content in *P. bogaraveo* (200 mg/100 g) and an exceptionally high value in raw *H. dactylopterus* (800 mg/100 g). However, *H. dactylopterus* maintained this high value only in the boiled sample, while *P. bogaraveo* retained a favourable level only in the grilled sample. Thus, considering the PUFA composition after cooking, grilling appears to be the most suitable method for *P. bogaraveo*, whereas boiling is the most appropriate for *H. dactylopterus*.

The FLQ (Fish Lipid Quality) index serves as an indicator of the nutritional value of a lipid source, reflecting the percentage contribution of key n-3 PUFAs (EPA + DHA) to total lipids (Abrami et al., 1992). As expected, based on the observed trends, *P. bogaraveo* exhibited the highest FLQ value when grilled (10.1) while *H. dactylopterus* reached its highest FLQ value when boiled (16.0), further supporting the suitability of these cooking methods for each species.

The British Department of Health recommends minimum PUFA:SFA and UFA:SFA ratio values of 0.45 and 0.35, respectively, as higher values contribute to a heart-healthy diet and play a key role in cardiovascular disease prevention (Teixeira et al., 2020). In this study, the PUFA:SFA ratio for raw *P. bogaraveo* was below the recommended threshold, with frying being the only cooking method that achieved the target value (0.5). However, it is important to consider the impact of oil absorption during frying. For *H. dactylopterus*, the PUFA:SFA ratio met the recommended values in raw, boiled and fried samples. Additionally, all cooking methods for both species resulted in UFA:SFA ratios exceeding the recommended minimum, further highlighting their nutritional value.

The atherogenicity index (AI) reflects the anti-atherogenic potential of a food, indicating its ability to prevent plaque aggregation and reduced cholesterol and phospholipid levels. In contrast, the thrombogenicity index (TI) represents the tendency to promote blood clot formation (Duyar & Bayrakli, 2023; Ulbricht & Southgate, 1991). Lower AI and TI values suggest a higher proportion of anti-atherogenic fatty acids, enhancing the potential for coronary heart disease prevention. In seafood products, AI and TI values below 1.0 are generally recommended (Bentes et al., 2009; Fernandes et al., 2014). In this study, the AI and TI values for cooked *P. bogaraveo* met these dietary recommendations only in fried and grilled samples. Conversely, for *H. dactylopterus*, all cooking methods resulted in values consistent with a heart-healthy diet, except for the AI value in the baked sample, which slightly exceeded the recommended threshold (1.1).

The hypocholesterolemic/Hypercholesterolemic (h/H) ratio is directly proportional to PUFA content, with higher values indicating greater potential health benefits (Bentes et al., 2009). In this study, *P. bogaraveo* exhibited the highest h/H values after frying (1.8) and grilling (1.2), while *H. dactylopteros* showed the most favourable values for frying (3.3) and boiling (1.5). However, as previously noted, the influence of oil absorption during frying must be considered. When cross-referencing these findings with the HPI (Health-Promoting Index) and PI (Polyene Index), both of which assess lipid oxidative stability during cooking, it is evident that, in terms of cardiovascular health benefits, grilled *P. bogaraveo* and boiled *H. dactylopterus* are the most advantageous choices among the studied cooking methods.

Trans fatty acids (TFAs) can have health effects. For example, industrial TFAs increase LDL (low-density lipoprotein) cholesterol levels and decrease HDL (high-density lipoprotein) cholesterol levels, increasing the risk of coronary heart disease and atherosclerosis and inducing apoptosis and inflammation (Pipoyan et al., 2021). The thermal processing that occurs in the cooking methods under study led to the formation of TFAs, which are potentially harmful to human health. Some TFAs were detected in the fish samples analysed and, although they may occur naturally in some animal products, it is important to note that they lead to an increase or decrease in the nutritional quality of the samples.

5. Final Considerations

This study analyzed the composition and nutritional indices and discussed the potential health benefits of consuming *P. bogaraveo* and *H. dactylopterus* after culinary processing. Overall, the findings support the high nutritional quality of these Azorean demersal species as part of a healthy diet, regardless of the cooking method applied. However, significant differences were observed between cooking methods for both species, demonstrating that the choice of preparation can positively or negatively impact their nutritional quality and health benefits.

Grilling was identified as the most effective method for preserving these species as a rich source of minerals. Additionally, all cooking methods resulted in UFA:SFA ratios above the recommended threshold, confirming their nutritional value. When considering PUFA composition, FLQ, AI, TI, HPI, PI and h/H indices, grilling emerged as the most appropriate method for *P.*

bogaraveo, while boiling was the most beneficial for *H. dactylopterus,* particularly in terms of cardiovascular health.

Given the increasing demand for fish as a source of high-quality protein, it is essential to evaluate the nutritional impact of different processing methods. This study reinforces the dietary value of these commercially important demersal species, even after cooking, emphasizing the need to match specific culinary techniques to each species for optimal nutritional retention.

Future research should expand the analysis to a broader range of Azorean demersal species, further exploring the effects of culinary processing on amino acid composition, macro and trace elements, toxic elements and vitamin content. Additionally, further investigation is needed to assess the bioaccessibility and bioavailability of key nutrients in these food matrices, enabling a comprehensive risk-benefit evaluation of their consumption in particular and the impact of fish consumption on human health in general.

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Authors’ Contributions

Conceived and designed experiment: J.G., I.M., A. M. Performed experiment: J.G., I. M. Processed the samples: J.G., A.P., A. O. Analyzed data: J.G., I. M. All authors contributed to the writing of the paper. All authors contributed to the article, read and approved the final manuscript.

Availability of data and materials

All data generated or analyzed during this study are included in this published article [and its supplementary information files].

Conflicts of Interests

The authors declare that they have no competing interests.

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Further Declarations

This study was approved by the following institutions: FCT (Foundation for Science and Technology), OKEANOS Institute and IPMA (Portuguese Institute for the Ocean and Atmosphere) in accordance with ARRIVE guidelines (https://arriveguidelines.org). This work has been conducted in accordance with institutional, national and international guidelines concerning the use of animals in research and/or the sampling of endangered species. None of the species studied is considered endangered or under any other minor threat category. This manuscript reflects the authors’ view alone, and the European Union or Regional Government of the Azores cannot be held responsible for any use that may be made of the information contained herein.

References

Abrami, G., Natiello, F., Bronzi, P., McKenzie, D., Bolis, L., & Agradi, E. (1992). A comparison of highly unsaturated fatty acid levels in wild and farmed eels (Anguilla anguilla). *Comparative Biochemistry and Physiology. B, Comparative Biochemistry, 101*(1-2), 79-81.https://doi.org/10.1016/0305-0491(92)90161-J

Ahmed, I., Jan, K., Fatma, S., & Dawood, M. A. O. (2022). Muscle proximate composition of various food fish species and their nutritional significance: A review. *Journal of Animal Physiology and Animal Nutrition*, *106*(3), 690–719. https://doi.org/10.1111/jpn.13711

An, F., Kang, X., Zhang, L., Leilei, JinbaoWang, Shao, B., & Wang, J. (2013). Comparison of muscle properties and meat quality between Jing Ning chicken and Ling Nan Huang Yu meat chicken . *Journal of Food, Agriculture and Environment*, *11*(1), 54–58. https://doi.org/https://doi.org/10.1234/4.2013.3768

Asghari, L., Zeynali, F., & Sahari, M. A. (2013). Effects of boiling, deep-frying, and microwave treatment on the proximate composition of rainbow trout fillets: changes in fatty acids, total protein, and minerals. *Journal of Applied Ichthyology*, *29*(4), 847–853. https://doi.org/10.1111/jai.12212

Barua, P., Pervez, M. A., Sarkar, D., & Sarker, S. (2022). Proximate biochemical composition of some commercial marine fishes from Bay of Bengal, Bangladesh. *Mesopotamian Journal of Marine Sciences*, *27*(1), 59–66. https://doi.org/10.58629/mjms.v27i1.172

Begum, M., Bhowmik, S., Juliana, F. M., & Hossain, M. S. (2016). Nutritional profile of hilsa fish [Tenualosa ilisha (Hamilton, 1822)] in six selected regions of Bangladesh. *Journal of Nutrition & Food Sciences*, *06*(06). https://doi.org/10.4172/2155-9600.1000567

Bentes, Á. de S., Souza, H. A. L. de, Simões, M. G., & Mendonça, X. M. F. D. (2009). Caracterização física e química e perfil lipídico de três espécies de peixes amazônicos. *Revista Brasileira de Tecnologia Agroindustrial*, *3*(2). https://doi.org/10.3895/S1981-36862009000200011

Berber, S., Acarlı, S., Bayraklı, B., Kale, S., Kızılkaya, B., Vural, P., & Acarlı, D. (2024). Monthly variation of fatty acids, lipid quality index and metal content of Pontastacus leptodactylus (Eschscholtz, 1823) in Atikhisar Dam Lake (Çanakkale, Türkiye). *Environmental Science and Pollution Research*, *31*(18), 27014–27036. https://doi.org/10.1007/s11356-024-32858-1

Chen, S., Bobe, G., Zimmerman, S., Hammond, E. G., Luhman, C. M., Boylston, T. D. & Beitz, D. C. (2004). Physical and sensory properties of dairy products from cows with various milk fatty acid compositions. *Journal of Agricultural and Food Chemistry, 52*(11), 3422-3428. https://doi.org/10.1021/jf035193z

Costa, E. F. S., Menezes, G. M., & Colaço, A. (2024). Trait-based insights into sustainable fisheries: A four-decade perspective in Azores archipelago. *Science of The Total Environment*, *935*, 173271. https://doi.org/10.1016/j.scitotenv.2024.173271

Domiszewski, Z., Bienkiewicz, G., Plust, D., & Kulasa, M. (2011). Quality of lipids in marinated herring. *Electronic Journal of Polish Agricultural Universities*, *14*(1). http://www.ejpau.media.pl/volume14/issue1/art-09.html

Duarte, A. M., Silva, F., Mendes, S., Pinto, F. R., Barroso, S., Silva, E., Neves, A., Sequeira, V., Magalhães, M. F., Rebelo, R., Assis, C., Vieira, A. R., Gordo, L. S., & Gil, M. M. (2022). Seasonal study of the nutritional composition of unexploited and low commercial value fish species from the Portuguese coast. *Food Science & Nutrition*, *10*(10), 3368–3379. https://doi.org/10.1002/fsn3.2937

Duyar, H. A., & Bayrakli, B. (2023). Fatty acid profiles of fish oil derived by different techniques from by-products of cultured black sea salmon, Oncorhynchus mykiss. *Journal of Agricultural Sciences*, *29*(3), 833–841. https://doi.org/10.15832/ankutbd.1187017

Fernandes, C. E., Vasconcelos, M. A. da S., Ribeiro, M. de A., Sarubbo, L. A., Andrade, S. A. C., & Melo Filho, A. B. de. (2014). Nutritional and lipid profiles in marine fish species from Brazil. *Food Chemistry*, *160*, 67–71. https://doi.org/10.1016/j.foodchem.2014.03.055

Fernández-Palacios, Y., Kaushik, S., Abramic, A., Cordero-Penín, V., García-Mendoza, A., Bilbao-Sieyro, A., Pérez-González, Y., Sepúlveda, P., Lopes, I., Andrade, C., Nogueira, N., Carreira, G. P., Magalhães, M., & Haroun, R. (2023). Status and perspectives of blue economy sectors across the Macaronesian archipelagos. *Journal of Coastal Conservation*, *27*(5), 39. https://doi.org/10.1007/s11852-023-00961-z

García-Arias, M. T., Álvarez Pontes, E., García-Linares, M. C., García-Fernández, M. C., & Sánchez-Muniz, F. J. (2003). Cooking–freezing–reheating (CFR) of sardine (Sardina pilchardus) fillets. Effect of different cooking and reheating procedures on the proximate and fatty acid compositions. *Food Chemistry*, *83*(3), 349–356. https://doi.org/10.1016/S0308-8146(03)00095-5

Huynh, M. D., & Kitts, D. D. (2009). Evaluating nutritional quality of pacific fish species from fatty acid signatures. *Food Chemistry*, *114*(3), 912–918. https://doi.org/10.1016/j.foodchem.2008.10.038

International Organization for Standardization. (2012). Animal feeding stuffs - Guidelines for sample preparation: reference method. In *ISO 6498:2012*.

Tilami, S. K., & Sampels, S. (2018). Nutritional value of fish: Lipids, proteins, vitamins, and minerals. *Reviews in Fisheries Science & Aquaculture*, *26*(2), 243–253. https://doi.org/10.1080/23308249.2017.1399104

Khan, I., Hussain, M., Jiang, B., Zheng, L., Pan, Y., Hu, J., Khan, A., Ashraf, A., & Zou, X. (2023). Omega-3 long-chain polyunsaturated fatty acids: Metabolism and health implications. *Progress in Lipid Research*, *92*, 101255. https://doi.org/10.1016/j.plipres.2023.101255

Larsen, D., Quek, S. Y., & Eyres, L. (2010). Effect of cooking method on the fatty acid profile of New Zealand King Salmon (Oncorhynchus tshawytscha). *Food Chemistry*, *119*(2), 785–790. https://doi.org/10.1016/j.foodchem.2009.07.037

Lubis, Z., & Buckle, K. A. (1990). Rancidity and lipid oxidation of dried-salted sardines. International *Journal of Food Science & Technology, 25*(3), 295–303. https://doi.org/10.1111/j.1365-2621.1990.tb01085.x

Marques, I., Botelho, G., & Guiné, R. (2019). Comparative study on nutritional composition of fish available in Portugal. *Nutrition & Food Science*, *49*(5), 925–941. https://doi.org/10.1108/NFS-11-2018-0311

Maulvault, A. L., Anacleto, P., Lourenço, H. M., Carvalho, M. L., Nunes, M. L., & Marques, A. (2012). Nutritional quality and safety of cooked edible crab (Cancer pagurus). *Food Chemistry*, *133*(2), 277–283. https://doi.org/10.1016/j.foodchem.2012.01.023

Méndez, E., & González, R. M. (1997). Seasonal changes in the chemical and lipid composition of fillets of the Southwest Atlantic hake (Merluccius hubbsi). *Food Chemistry*, *59*(2), 213–217. https://doi.org/10.1016/S0308-8146(96)00225-7

Mieiro, C. L., Coelho, J. P., Dolbeth, M., Pacheco, M., Duarte, A. C., Pardal, M. A., & Pereira, M. E. (2016). Fish and mercury: Influence of fish fillet culinary practices on human risk. *Food Control*, *60*, 575–581. https://doi.org/10.1016/j.foodcont.2015.09.006

Nogueira, N., Cordeiro, N., & Aveiro, M. J. (2013). Chemical composition, fatty acids profile and cholesterol content of commercialized marine fishes captured in Northeastern Atlantic. *Journal of FisheriesSciences.Com*, *7*(3), 271–286. https://doi.org/10.3153/jfscom.2013029

Norma Portuguesa. (2000). NP EN ISO 872:2000. Qualidade da água - Determinação dos sólidos em suspensão - Método por filtração com filtros de fibra de vidro. *Instituto Português Da Qualidade*.

Norma Portuguesa. (2002). NP 1615:2002. Carne e produtos cárneos: determinação da cinza total: Método de Referência. *Instituto Português Da Qualidade*.

Norma Portuguesa. (2009). NP 1614-1:2009. Carne e produtos cárneos: determinação do teor de humidade – Parte 1: Método de Referência. *Instituto Português Da Qualidade*.

Norma Portuguesa. (2014). NP ISO 6492-2014. Alimentos para animais. Determinação do teor de gordura. *Instituto Português Da Qualidade*.

Pereira, I., Peixoto, U. I., Medeiros-Leal, W., Casal-Ribeiro, M., & Santos, R. (2022). Multidimensional Indicators to Assess the Sustainability of Demersal Small-Scale Fishery in the Azores. *Sustainability*, *14*(24), 16585. https://doi.org/10.3390/su142416585

Pipoyan, D., Stepanyan, S., Stepanyan, S., Beglaryan, M., Costantini, L., Molinari, R., & Merendino, N. (2021). The effect of trans fatty acids on human health: Regulation and consumption patterns. *Foods*, *10*(10), 2452. https://doi.org/10.3390/foods10102452

Ryu, B., Shin, K.-H., & Kim, S.-K. (2021). Muscle protein hydrolysates and amino acid composition in fish. *Marine Drugs*, *19*(7), 377. https://doi.org/10.3390/md19070377

Saldanha, T., & Bragagnolo, N. (2010). Effects of grilling on cholesterol oxide formation and fatty acids alterations in fish. *Ciência e Tecnologia de Alimentos*, *30*(2), 385–390. https://doi.org/10.1590/S0101-20612010000200015

Santos, R. V. S., Silva, W. M. M. L., Novoa-Pabon, A. M., Silva, H. M., & Pinho, M. R. (2019). Long-term changes in the diversity, abundance and size composition of deep sea demersal teleosts from the Azores assessed through surveys and commercial landings. *Aquatic Living Resources*, *32*, 25. https://doi.org/10.1051/alr/2019022

Sioen, I., Haak, L., Raes, K., Hermans, C., De Henauw, S., De Smet, S., & Van Camp, J. (2006). Effects of pan-frying in margarine and olive oil on the fatty acid composition of cod and salmon. *Food Chemistry*, *98*(4), 609–617. https://doi.org/10.1016/j.foodchem.2005.06.026

Song, J., Kim, Y.-S., Lee, D. H., Lee, S. H., Park, H. J., Lee, D., & Kim, H. (2019). Neuroprotective effects of oleic acid in rodent models of cerebral ischaemia. *Scientific Reports*, *9*(1), 10732. https://doi.org/10.1038/s41598-019-47057-z

Tan, K., Huang, L., Tan, K., Lim, L., Peng, Y., & Cheong, K.-L. (2023). Effects of culinary treatments on the lipid nutritional quality of fish and shellfish. *Food Chemistry: X*, *19*, 100856. https://doi.org/10.1016/j.fochx.2023.100856

Teixeira, A., Fernandes, A., & Pereira, E. (2020). Fat content reduction and lipid profile improvement in Portuguese fermented sausages alheira. *Heliyon*, *6*(10), e05306. https://doi.org/10.1016/j.heliyon.2020.e05306

Torres, P., Milla i Figueras, D., Diogo, H., & Afonso, P. (2022). Risk assessment of coastal fisheries in the Azores (north-eastern Atlantic). *Fisheries Research*, *246*, 106156. https://doi.org/10.1016/j.fishres.2021.106156

Ulbricht, T. L. V., & Southgate, D. A. T. (1991). Coronary heart disease: seven dietary factors. *The Lancet*, *338*(8773), 985–992. https://doi.org/10.1016/0140-6736(91)91846-M

Uran, H., & Gokoglu, N. (2014). Effects of cooking methods and temperatures on nutritional and quality characteristics of anchovy (Engraulis encrasicholus). *Journal of Food Science and Technology*, *51*(4), 722–728. https://doi.org/10.1007/s13197-011-0551-5

Valério, N., Soares, M., Vilarinho, C., Correia, M., & Carvalho, J. (2023). Diving into Fish Valorisation: Review Opportunities and Analyzing Azorean Fish Data. *Processes*, *11*(7), 1998. https://doi.org/10.3390/pr11071998

Weber, J., Bochi, V. C., Ribeiro, C. P., Victório, A. de M., & Emanuelli, T. (2008). Effect of different cooking methods on the oxidation, proximate and fatty acid composition of silver catfish (Rhamdia quelen) fillets. *Food Chemistry*, *106*(1), 140–146. https://doi.org/10.1016/j.foodchem.2007.05.052

WHO. (2002). Population nutrient intake goals for preventing diet-related chronic diseases. In *Diet, nutrition and the prevention of chronic diseases: report of a joint WHO/FAO expert consultation* (pp. 54–59). WHO/FAO.